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Capacity Output and Possibility of Cost Reduction: Fishery Management in Japan

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Abstract

Japan's fishery harvest peaked in the late 1980s. Providing individually specific catch shares of the Total Allowable Catch (TAC) to each fisherman is the key to avoid the race for fish. Thus, in moving the idea into practice with the actual implementation of catch shares, it is curial to estimate the potential cost reduction in the industry. We find that the maximum level of production the fixed inputs in Japan are capable of supporting (i.e., capacity output) could be three times higher. Additionally, current overall fixed inputs could be reduced to one-tenth. Getting rid of these inefficient fishers would help lead to sustainable fishery management. These significant potential results are important for policy purpose. For example, about 450 billion yen (about 4.5 billion dollars) can be saved allocating individually specific catch shares to each fisherman.

Keywords: Capacity Output; Capacity Utilization; Individual Quotas; Production Frontier; Japan.

1. Introduction

That harvesters plunder resources as much as they can as a result of misaligned incentives, is a “tragedy of the commons.” Literature in resource economics has focused on the sustainable use of renewable resources since the mid-1950s (i.e., Gordon, 1954). In many countries, fishery is known as a classic case of mismanagement of common-pool resource. For example, the total volume of fish caught from 1979 through 2005 for developed countries has steadily declined (Food and Agriculture Organization (FAO), 2008). Furthermore, the world may run out of seafood if sharp declines in marine species continue at the current rate (see Worm et al., 2006).

In the literature of theoretical and empirical fishery economics, the recommended policy prescription for fisheries management is the catch shares system. The catch shares grant each fisherman the right to harvest a given percentage of the total allowable. Each fisherman has an incentive to manage it well because the value of these shares increases with the productivity of the fishery product. For example, Costello et al. (2008) show that the fisheries management strategy of catch shares can reverse a collapse in fisheries. They find that the proportion of fisheries managed by Individual Transferable Quotas (ITQs) - one of the catch shares systems - that had gone into bankruptcy by 2003, was half that of the non-ITQ fisheries. That is, the alternative policy is better for both fish and fishermen.

In many countries, however, implementation of the catch shares system has been difficult because of political, ideological, and regulatory issues. For example, there are strong obstacles for the implementation in Japan of incentive based policies such as ITQs because no previous studies have estimated the potential of alternative policies and there is concern about any uncertain outcome (Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF), 2008). At present, Japan is one of the world's most prominent fishery nations, both for production (i.e., catch) and consumption. The ocean fisheries in Japan are freely accessible (or have open access) because their Total Allowable

Catch (TAC) caps have been too loose to restrict the activity of fishermen. This has brought about a competitive race for fish. Although wasteful, the main reason for this "fish race," is the *lack of individually specific TAC catch shares* rather than the provision of property rights in the ITQ or any other management instruments (Macinko and Bromley, 2002). There are too many boats chasing the same fish in this "fish race," which results in rent dissipation. The fish stock has been decimated by the associated catch level, which is not sustainable in resource management. Even though Japan's total fish catch was the largest in the world until the late 1980s, it came in 6^{th} in 2006 (FAO, 2008). Thus, the core question in our study is, "is there significant potential in Japan's fishery industry assuming that we are able to set the optimal individually specific catch shares?"

Given the importance of fishery management and production in Japan, this study analyzes the quantitative potential of optimal input/output allocations by assigning optimal Individual Quotas (IQs). Our results show the ideal case of the potential catch shares system in one regard. The catch shares system divides the total permitted catch in a fishery into shares. That is, under the systems, yearly limits, or quotas, are set on a fishery.[1] This is because, given the scientifically allowable total catch, allocation of a percentage share of that total to fishermen can be set to the level of our calculated optimal outputs each region/fisherman.

2. Background

2.1. Case in Japan

The fish catch in Japan has been decreasing drastically due to overfishing since 1989, even though it had showed a continuous increase from the late 1970s (Figure 1). Given the declining fish catches,

[1] The allocated shares are bought and sold like shares of stock in a company. Shareholders in the fishery are each guaranteed a percentage of the catch. The number of fish that each fisherman may catch is usually based on past averages. The catch share systems are already common in Australia, New Zealand and Iceland, while they have been gaining popularity in Canada and the United States. Though our model directly shows how much each individual needs to catch (and use as effort), we do not allow market mechanism in the model. In this sense, it is different from the catch shares concept. However, we are able to show optimal individual catch combinations, so that total catch is divided to each catch share.

the Japan Fisheries Agency enacted the “Basic Law on Fisheries Policy” in June 2001. The law is a new guideline for fishery policy replacing the “Coastal Fishery and Others Promotion Law” of 1963, whose primary aim was to improve fishery productivity. The Basic Law has two key concepts: 1) securing a stable supply of fishery products; and 2) the sound development of the fisheries industry to promote the appropriate conservation and management of marine living resources.

In 1995, the Japan Fisheries Agency started to reduce the number of fishing vessels and restrictions on fishing area and/or period for some fisheries in order to ensure the sustainable use of fishery resources. The Total Allowable Catch (TAC) system has also been implemented. The principal laws are “The Fisheries Law”, the “Living Aquatic Resources Protection Law” and the “Law Concerning Conservation and Management of Marine Living Resources.” These principal laws were also amended in keeping with the concept of the “Basic Law on Fisheries Policy.” The central and prefectural governments regulate fishing efforts in terms of fishing methods. The TAC system assigns TAC allocations to each fishery separately, not to individual fishermen. While seven fish species are subject to the TAC system, covering about 30% of total fishing in Japan in 2000, Total Allowable Effort (TAE) was established as a system to manage total allowable effort with the amendment of the “Law Concerning Conservation and Management of Marine Living Resources.” The TAE includes curtailing the number of boats, suspension of operations, and improvement of fishing gear among others. However, these regulations are not effective and the catch has been decreasing continuously. Essentially, the regulations are too loose to control the actual activities of fishermen.

For decades, the Fisheries Agency subsidized an expansion of its own national fleets, leading to increased fishing in coastal regions for financial supports. Without subsidies, most fishermen need to exit from the market. Therefore, our interest is in understanding production performance in the disaggregated regional species level. Because of the distortion of resource allocation by subsidy to each input in the fisheries, we expect that abundant inputs are used but they are not fully utilized. For instance, if we find a significant abundance of boat usage, subsidies to the fishermen might be re-organized so that resources are all utilized. Overfishing is increasingly threatening marine resources and, as a consequence, Japanese fishery catches have been decreasing over the last two decades because of it. Catches in 2006, for example, totaled about 55 thousand metric tons. This is only 44 % of 1987 production (FAO, 2008).

Labor productivity (i.e., fishery production value per worker, where fishery production refers to the output of fish by humans from capture fisheries) and capital productivity (i.e., value per fishing vessel) are relatively stable for total catch amount excluding Sardine. During the past 30 years, there has been a maximum of 20% difference or fluctuation. In the meantime, production has decreased 56%. This indicates the possibility of overinvestment and resource competition on a first-come-first-served basis among fishery entities, i.e., mismanagement in fisheries. Therefore, over-fishing needs to be eliminated, but how many fishing vessels can be cut is not yet known. Because this productivity (or efficiency) is relatively stable over time (though there are random fluctuations in the catch), we are therefore able to use it as the indicator to show the potential of the fishery industry. Hereafter, we discuss the efficiency index in detail.

2.2. Theoretical Analysis

Measure for excess capacity of fishing fleets, more specifically, capacity output and Capacity Utilization (CU), is often applied in the literature. Capacity output represents the maximum level of production the fixed inputs are capable of supporting (see Johansen, 1968; Morrison, 1985; Färe et al., 1994; Kirkley and Squires 2003). CU is the proportion of available capacity that is utilized, and is usually defined as the ratio of actual (i.e., current) output to some measure of capacity (i.e., potential) output (see Morrison, 1985; Nelson, 1989; Kirkley and Squires 2003). Therefore, CU is measured on a 0 to 1 scale. When CU is less than 1, one could produce more catch than current catch if inputs are fully utilized. In other words, smaller inputs are enough (assuming they are fully utilized) to produce same level of current catch. The purpose of this study is to measure the capacity output and CU of Japan's fisheries. Then, we examine how much cost reductions they can achieve in a well-controlled world using unique disaggregated data covering all areas in Japan. If there is less capacity output in Japan's fisheries, there would be less reduction of fishing vessels and more investment flexibility assuming potential fluctuations in the future. On the other hand, if there is large capacity output, there should be an increased reduction of fishing vessels.

The more detailed purpose of this study is to find the optimal inputs/outputs mix of Japanese fisheries. In this study, we apply the revised Johansen industry model to measure the capacity outputs following Kesterns et al. (2006). This model consists of two steps of different linear programming (LP) techniques. First, we measure the capacity output by using output-oriented DEA. Second, we measure the optimal fixed inputs given in certain fishery quotas.

Optimal scales of outputs and fixed factor inputs indicate the required total outputs and inputs at industry level. Calculated loss of efficiency shows the possible reduction of the fixed inputs. The capacity outputs assume variable return to scale (VRS) in our model to be flexible. The production frontier is calculated based on the maximum outputs given current inputs.

2.3. Literature Review

Recently, a sophisticated model of the multi-output/input frontier-based short-run Johansen industry model has been developed by Kesterns et al. (2006). In the literature of fishery economics, there are few studies on the capacity at the industry level other than Färe et al. (2001) and Kesterns et al. (2006). In the industry model, capacities of individual fishery entities are utilized by minimizing fixed industry inputs given their total outputs, capacities and the current state of technology. We assume the variable inputs are allowed to vary and be fully utilized. Based on Färe et al. (2001), Kesterns et al. (2006) sophisticated empirical models are developed to analyze capacity outputs of the Danish fleets, extending to scenario analyses of tightening quota, seasonal closure policies, lower and upper bounds, decommissioning schemes and area closures. The results show that vessel numbers can be reduced by about 14 percent and the use of fixed inputs by around 15 percent, depending on the specific objective and policy mix in the Danish fishery.

We introduce three empirical studies using the Data Enveloped Analysis (DEA) to estimate fishery CU. Niels et al. (2003) measure three types of CU applied to the Danish Gillnet fleet using output-oriented DEA. As a result, the average CU of the Danish Gillnet fleet was found to be between 0.85 and 0.95, and excess capacities for cod and sole are higher than for other species. The result using the variable input utilization shows the output could have been increased on average by 27 percent in the period examined. Therefore, the numbers of fishing operations will be increased by 27 percent.

Many developing countries follow offshore fisheries development strategies (e.g., Kirkley et al., 2003). This is to increase protein supply, expand employment, earn foreign exchange, and mitigate the conflict between large- and small-scale fisheries over the inshore resource stocks. To evaluate the successful fishery policies of the Peninsular Malaysian fishery, Kirkley et al. (2003) analyze the west coast purse seine fishery in Malaysia to estimate the CU, and the crew utilization among others. The results tell us the Malaysian fishery has a very high level of technical efficiency.

Dupont et al. (2002) examine capacity and capacity utilization of the Nova Scotia mobile gear fishery by using individual firm data before and after the implementation of Individual Transferable Quotas (ITQs). The purpose of their study is examining how a change in the property rights regime can affect a multi-product industry and the consequences in terms of product-specific

CU, as well as aggregate CU. The result provides insights for market based approaches to improve efficiency in multi-product industries.

Among earlier studies applying DEA to the fishery industry to computing CU, there are few empirical studies discussing how much the industry inputs could be reduced, other than Kesterns et al. (2006). In addition, there are few studies evaluating Japanese fishery efficiency because the fisheries are extensive and diversified and there may be difficulties obtaining Japanese fisheries data. In this study, we focus on the efficiency of all Japanese fisheries, especially the reduction of the fixed factor inputs.

3. Model

3.1. Industry Model

Following the revised short-run Johansen model of Kesterns et al. (2006), we compute marine fishery efficiencies in Japan. The conceptual model proceeds in two steps. In the first step, the capacity measure is compared to determine capacity production for each fishery entity at the production frontier. The capacity production is calculated by output-oriented DEA model assuming strong disposal of inputs and outputs, and variable returns to scale. In the second step, individual entity capacities are utilized with the minimization of fixed industry inputs given total outputs, capacities, and current state of technologies. This capacity measure is short-run because it does not assume any change in the existing firm-level capacity, and it is a technical rather than an economic capacity notion.

The following models are applied in this study. The production technology S transforms inputs $x = (x_1, ..., x_n) \in R_+^n$ into outputs $u = (u_1, ..., u_m) \in R_+^m$ and summarizes the set of all feasible input and output vectors: $S = \{(x, u) \in R_+^{n+m} : x \text{ can produce } u\}$. Let J be the number of regional units. The n-dimensional input vector x is partitioned into fixed factors (indexed by f) and variable factors (indexed by v): $x = (x_f, x_v)$. To determine the capacity output and CU, a radial output-oriented efficiency measure is computed relative to a frontier technology providing the potential output given the current inputs use: $E^0(x, y) = \max\{\theta : (x, \theta y) \in S\}$.

Plant capacity output is defined as the maximum amount that can be produced per unit of time with existing equipment (given the availability of variable factors of production is not restricted). In the context of fisheries, this definition corresponds to the maximum catch a vessel can produce if present technology is fully utilized given the biomass and the age structure of the fish stock. We note that this definition does not measure the capacity of output level that can only be realized at prohibited high cost of input usage (and hence be economically unrealistic). The production technology $\hat{S}$ of plant capacity can be represented:

$$\widehat{S}^{\mathrm{VRS}} = \left\{ (x, u) \in R_+^{N+M} : u_{jm} \le \sum_{j=1}^{J} z_j u_{jm},\ m = 1, \dots, M; \right.$$
$$\sum_{j=1}^{J} z_j x_{jf} \le x_{jf},\ f = 1, \dots, F; \tag{1}$$
$$\left. \sum_{j=1}^{J} z_j = 1, z_j \ge 0, j = 1, \dots, J \right\}$$

The output-oriented efficiency measure θ_1 is measured by the following LP problem for each firm *j* (*j* =1, 2, …, *J*) relative to the short-run production possibilities set:

$$\max_{\theta_1^j, z_j} \{\theta_1^j : (x, \theta_1^j u) \in \widehat{S}^{\mathrm{VRS}}\} \tag{2}$$

To be consistent with the plant capacity definition, only the fixed inputs are bounded at their observed level and the variable inputs in the production model are allowed to vary and be fully utilized. The computed outcome of the model is a scalar θ_1. The θ_1 shows by how much the production of each output of each region can be increased. In particular, capacity output for region *k* of the *m*th output is θ_1^{*k} multiplied by actual production; u_{km}. Therefore, capacity utilization based on observed output (subscripted 'oo') is as follows:

$$\mathrm{CU}^{k}_{\mathrm{oo}} = \frac{1}{\theta_1^{*k}} \tag{3}$$

This ray CU measure may be biased downward (see Färe et al., 1994). This is because there is no guarantee the observed outputs are not produced in a technically efficient way. The problem of technically efficient measure is solved given that both the variable and fixed inputs are constrained to their current level. Another technical efficiency measure is obtained by evaluating each region j = 1, 2, ..., J relative to the production possibility set S^{VRS}:

$$S^{\mathrm{VRS}} = \left\{ (x,u) \in R_{+}^{N+M} : u_{jm} \le \sum_{j=1}^{J} z_j u_{jm},\ m = 1,\dots,M; \right. \\ \left. \sum_{j=1}^{J} z_j x_{jn} \le x_{jn},\ n = 1,\dots,N;\ \sum_{j=1}^{J} z_j = 1, z_j \ge 0,\ j = 1,\dots,J \right\}. \tag{4}$$

The outcome (θ_2) shows by how much production can be increased using the technically efficient inputs:

$$\max_{\theta_2^j, z_j} \{\theta_2^j : (x, \theta_1^j u) \in S^{\mathrm{VRS}}\} \tag{5}$$

The technically efficient output vector is θ_2 multiplied by observed production for each output. The technically efficient output (subscripted 'eo'), or unbiased ray measure of capacity utilization, is calculated as:

$$\mathrm{CU}^{k}_{\mathrm{eo}} = \frac{\theta_2^{*k}}{\theta_1^{*k}} \tag{6}$$

We focus on reallocating catches between vessels by explicitly allowing improvements in technical efficiency and capacity utilization rates. The model is developed in two steps as follows. An optimal activity vector z^{*k} is provided for region k from model (1), and thus capacity output and the optimal use of fixed and variable inputs are computed in the first step:

$$u_{km}^{*} = \sum_{j} z_j^{*k} u_{jm} - s_{jm}^{*k};\ x_{kf}^{*} = \sum_{j} z_j^{*k} x_{jf} + s_{jf}^{*k};\ x_{kv}^{*} = \sum_{j} z_j^{*k} x_{jv} \tag{7}$$

where s_{jm}^{*k} and s_{jf}^{*k} are the optimal surplus and slack variables corresponding to the output, respectively, fixed input dimensions.

In a second step, these 'optimal' frontier figures (i.e., capacity output and capacity variable and fixed inputs) at regional level are used as parameters in the industry model. Particularly, the industry model minimizes the industry use of fixed inputs in a radial way such that the total production is at least the current total level (or at a quota level in the model extended later) by a reallocation of production between regions. Reallocation is allowed based on the frontier production and input usage of each region. In the short run, we assume that current capacities cannot be exceeded either at the regional or industry level. Define U_m as the industry output level of output m and X_f (X_v) as the aggregate fixed (variable) inputs available to the sector of factor f (v), i.e.:

$$U_m = \sum_j u_{jm},\ X_f = \sum_j x_{fj},\ X_v = \sum_j x_{vj}\ . \tag{8}$$

The formulation of the multi-output and frontier-based industry model can then be specified as:

$$\begin{aligned} &\min_{\theta, w, X_v} \theta \\ &\text{s.t.} \sum_j u^*_{jm} w_j \geq U_m,\ m = 1,\ldots,M, \\ &\quad \sum_j x^*_{fj} w_j \leq \theta X_f,\ f = 1,\ldots,F, \\ &\quad -X_v + \sum_j x^*_{vj} w_j \leq 0,\ v = 1,\ldots,V, \\ &\quad 0 \leq w_j \leq 1,\ \theta \geq 0,\ j = 1,\ldots,J. \end{aligned} \tag{9}$$

3.2. Extension of Industry Model

We turn to the second-stage industry model (9). First, following the second modification above, the constraints for each output dimension have to reflect the fact that production may take place in different areas. That is, there are M output constraints (species) for each of the A areas:

$$\sum_j u^*_{jma} w_{ja} \geq U_{ma},\ m = 1,\ldots,M, a = 1,\ldots,A\ . \tag{10}$$

Each region j has one area a because the area corresponds to the place each aggregated entity belongs. Second, the industry consists of fishery entities or vessels fishing in different areas. The constraints for each of the total fixed inputs can be formulated in a most general way in terms of constraints indexed by area:

$$\sum_{j,a} x^*_{fja} w_{ja} \le \theta X_f,\ f = 1,...,F \tag{11}$$

Third, the constraints on the variable inputs are:

$$-X_v + \sum_{j,a} x^*_{vja} w_{ja} \le 0,\ v = 1,...,V \tag{12}$$

To offer a menu of current and potential conservation and distributional policies in fisheries, we add some further refinements to the short-run industry model of Dervaux et al. (2000). We here focus on four issues: (i) seasonal closures, putting limits on fishing days, (ii) partial tolerance of technical inefficiencies, (iii) the link between economic and plant capacity, and (iv) tightening quotas of either species.

(i) Seasonal closure policies limit the number of fishing days in an effort to control inputs. To limit the amount of variable inputs that appear in the model as an aggregate decision variable, we fix a constraint on the total annual fishing days at $\mathrm{FD}_{\max}$ common to all business entities. This can be simply represented as follows:

$$\sum_{a} x^*_{vja} w_{ja} \le \mathrm{FD}_{\max},\ v = 1 \tag{13}$$

given that the fishing days are indexed by *v* equal to 1 (i.e. the first variable input). In this study, $\mathrm{FD}_{\max}$ is 200 for all the entities when seasonal closure is imposed, and otherwise is 365 as unconstrained parameter.

(ii) The frontier nature of the underlying technologies may push things too far so that it is practically impossible to require vessels to adjust immediately to technically efficient production plans. While technical efficiency is a condition for any social optimum, realistic planning procedures may require tolerating technical inefficiency for part of this path for informational and political reasons (Peters, 1985).

This can be modeled by adjusting the capacity output, which enter to the second stage industry model, by its current observed technical inefficiency and ultimately corrected by an efficiency improvement imperative (α) (see Kesterns el al., 2006). Of course, technically efficient regions at present need no such adjustment. Therefore, assuming this correction factor is smaller or equal to unity ($\alpha = 1$), adjustment of the second stage capacity output could take the following form when technical inefficiency is (partially) accepted:

$$\begin{aligned} &\theta \geq 0,\ \hat{u}^{*}_{jma} = \frac{u^{*}_{jma}}{\max\{1, \alpha\theta^{*}_{1}\}} \\ &j = 1,\ldots,J,\ a = 1,\ldots,A \end{aligned} \tag{14}$$

In this research α is 0.1 for all the entities when technical inefficiencies are tolerated partially. When α is set to be 0.1, capacity outputs of all the entities is limited up to 10 times of current output.

(iii) Lower bounds (LB) and upper bounds (UB) are introduced on the activity vectors to avoid economically unviable solutions (i.e., LB) and production at technical capacity levels that are beyond economic capacity levels (i.e., UB), respectively. This indirectly includes economic information into an otherwise technical production model.

$$\text{LB} \leq w_{ja} \leq \text{UB},\ j = 1,\ldots,J,\ a = 1,\ldots,A \tag{15}$$

In this research LB is 0 or 0.1 and UB is 1 or 0.9 as unconstrained and constrained parameters, respectively.

(iv) We consider setting quotas such as TAC for particular species in Japan. We simply add the constraint:

$$\sum_{a} U_{ma} = U_{m} \cdot Q_{m},\ m = 1,\ 0 \leq Q_{m} \leq 1 \tag{16}$$

given that the species are indexed by *m* equal to 1 (i.e. the first output). Q_m indicates a quota rate for the *m*th current industry output. In this study Q_m is incremented by 0.01 from 0 to 1 for sensitivity analysis purpose.

We sum up the above mentioned constraints and our model is shown as follows:

$$
\begin{aligned}
&\min_{\theta, w, X_v} \theta \\
&\text{s.t.} \sum_j \hat{u}^*_{jma} w_{ja} \ge U_{ma},\ m = 1,...,M,\ a = 1,...,A \\
&\quad \sum_{j,a} x^*_{fj} w_{ja} \le \theta X_f,\ \ f = 1,...,F \\
&\quad -X_v + \sum_{j,a} x^*_{vj} w_{ja} \le 0,\ v = 1,...,V \\
&\quad \text{LB} \le w_{ja} \le \text{UB}, \\
&\quad \sum_a U_{ma} = U_m \cdot Q_m,\ m = 1 \\
&\quad \sum_a x^*_{vja} w_{ja} \le \text{FD}_{\max},\ v = 1 \\
&\quad \theta \ge 0,\ \ \hat{u}^*_{jma} = \frac{u^*_{jma}}{\max\{1, \alpha\theta^*_1\}} \\
&\quad j = 1,...,J,\ a = 1,...,A, 0 \le Q_m \le 1
\end{aligned}
\tag{17}
$$

4. Data and Scenarios

4.1. Data

Data used in this study comes from *the 11th Fishery Census of Japan on 2003* and *Annual Statistics of Fishery and Fish Culture 2003* by Ministry of Agriculture, Forestry and Fisheries of Japan. The data set is composed of each aggregated fishery entity per municipality per marine fishery type in Japan. The *2003 Fishery Census of Japan* was conducted to clarify the structures of fishery production in Japan, and to comprehend the overall background of fisheries concerning fishing villages, marketing and processing industries among others. The purpose is developing basic data for fisheries policies including improvements in the structure of fisheries.

Our output data is production value (in the unit of Japanese yen) and quantities data. There are nine types of outputs used in this study, including total production quantity, all fishes, the other marine animals, Japanese sardine, Japanese jack mackerel, Mackerel Pacific saury, Alaska Pollock, Queen crab, and Japanese Common Squid (Table 1). The TAC system in Japan applies to all these seven species. For example, the Squid showed a slight decline although it still remains in a dominant position. The Pollock has been on the decline mainly due to the subsequent fall of catch in the

Bering high seas. Mackerel have also decreased drastically over the years.

There are two variable inputs - labor and fishing days - and two fixed inputs of gross registered - tons (Grt) and horse power (kilowatt) - for aggregated fishery entities of each municipality and marine fishery type in Japan. The fixed inputs are both multiplied by the number of fishing days, following Kesterns et al. (2006). The variable inputs are numbers of workers on board at peak times and average fishing days of each aggregated entity. Descriptive statistics for each area are reported in Table A1 in the Appendix. These data cover effectively all the Japanese fishery entities. The aggregated fishery entities with missing values and fishing within 30 days are excluded in the sample. In total, 74,728 fishery entities are covered in the data set of 7,483 observations. On average, each aggregated fishery entity consists of about 10 entities (Table 1). We have 39 classifications of marine fisheries in analyses. Basic allocation of fishery in each are, technology type, and fishery species are provided in Table A2-A4 in the Appendix. Small whaling, diving apparatus fisheries, shellfish collecting, seafood collecting, and other fisheries are excluded because we consider these fisheries atypical cases.

We assume management decisions are provided in the disaggregated regional level, especially models (1) and (4), because their decision making is applied to one given area and one given fishery type. Thus, the efficiency of each aggregated fishery entity is evaluated relative to one of the potentially 361 different technologies (nine areas by thirty-nine marine fishery types). The technologies, which consist of only a few similar observations, may lead to biases in the estimation of plant capacity due to a lack of comparable production units. To avoid downward estimation, we use 10 large classifications and refer to the 10 and 39 fishery classifications as fishery type 1 and 2, respectively (see Table 1). Therefore, there are potentially 90 and 361 different technologies in fishery type 1 and 2. We use mainly fishery type 1, and compare type 1 with type 2 in an unconstrained scenario.

4.2. Scenarios

In each specification, we apply several different types of output variables. In the first two specifications, production value and production quantity are used as the output variables, respectively, and we compare both efficiencies. Second, we divide the estimated production quantity into two and three categories, which are (a) TAC species and the others including (b) fish and (c) the other marine animals. The aim of this division is to set production quotas only for respective TAC species, and to compare the efficiencies of each group.

We classify a series of scenarios, systematically testing the effect of additional constraints. The results of several policy-oriented scenarios with various constraints are useful for policy implications. These scenarios are summarized in Table 2. Basic scenario 1 is the basic industry model without any particular constraints. The seasonal closure scenario limits the number of average fishing days to 200 each year. The tolerated technical inefficiencies scenario allows for technical inefficiencies, but already imposes an improvement imperative of 1000 per cent (thus, α = 0.1). The UB scenario looks at the impact of UB on the activity or intensity vector, and the UB is fixed at 0.9. The LB scenario as well as the UB scenario look at the impact of LB, and the LB was set equal to 0.1. These five scenarios use fishery type 1. Basic scenario 2 uses fishery type 2 without any particular constraints.

We compute the optimal inputs in the industry model. We follow Kesterns et al. (2006) to set the optimal fixed inputs (Grt and kw) and variable inputs (labor and fishing days) as $\theta^* X_f / (w^* \cdot X_v^*)$ and $w^* \cdot X_v^*$, respectively. We also estimate optimal fishery expenditures (such as wage, vessels, implements, and oil) to understand how much expenditures could be reduced in a reallocated world. We calculate them using average expenditure percentages of total fishery income among fishery business entities from 1961 to 2000. The reason why we only refer to the expenditures of business entities is that labor costs of fishery households are difficult to interpret because the costs are considered to be included in their discretionary incomes. On average, wages, vessels, implements, and oil account for 36.5%, 7.2%, 3.9%, and 11.6% of total fishery income during the period, respectively (Table A5)[2].

5. Empirical Results

5.1. Scenario Analyses

(a) Current and Capacity Outputs

Scenarios 1 and 2 show the results comparing current output and capacity outputs (see Figure 2). In the figure, vertical and horizontal axes represent percentages of total production values and fixed inputs, respectively. The results are calculated with LP and show how much production *values* fixed inputs can maximally produce based on each scenario. Similarly, Figure 3 shows how much production *quantities* the fixed inputs can maximally produce based on each scenario.

The results indicate that there is a large excess capacity in Japanese fisheries. This reflects the fact that fisheries management is in a state of crisis. Since access is almost free, fishing activity is under-priced and therefore a huge amount of effort is devoted to fishing. When there are no differences among efficiencies of the aggregated entities, 1% of total fixed inputs produces 1% of total outputs, and the path of the current output will be linear. Note that efficiency implies average efficiency of each scenario if we do not specify otherwise. This is because current output is calculated with LP, which seeks combination of DMUs to minimize a requisite amount of the fixed

[2] This basic information is estimated as follows. First, we define the payment of wages is twelve thousand yen per person per day given that this payment is proportional to the product of average fishing days and labors. Second, the vessel cost is 1.2 million yen per tonnage and 50 thousand yen per horsepower (kilowatt) for 15 years given that this cost is proportional to optimal tonnages and horsepower (kw). Third, the implementation cost is 0.6 million yen per horsepower (kw) for 15 years given the optimal horsepower (kw). Last, the oil cost is 100 yen per horsepower (kw) per day given the optimal horsepower (kw) and fishing days.

inputs for a certain amount of output. On the other hand, the more varied efficiencies of each aggregated entity are, the more curved the line of capacity outputs since 1% of total outputs can be produced by less than 1% of fixed inputs.

Compared with the difference between current outputs of the production values and quantities, the current output of the production values has a less curved line than that of the quantities. It implies that each DMU decides the amounts of fixed inputs depending on expected values rather than expected quantities, and it is legitimate decision-making depending on estimation of income and expenditure of each fishery entity.

Compared with the difference between capacity outputs of the production values and quantities, the capacity outputs of the production values are smaller than those of the quantities. The difference between these numeric values may result from the difference of the degrees of varied efficiencies based on the entities' valid decision-makings with cost benefit considerations.

(b) Capacity Outputs

We show two results of the efficiencies using the production value data and the quantity data. First, Figure 4 shows capacity outputs of production values based on each scenario. Sensitivity analyses are provided by changing total quota, and, in each case, efficiency is computed. The quota is used as the horizontal line in the figure. Here, efficiency in this figure is defined as a reduction percentage of fixed inputs by applying equation 17.

According to the results, efficiencies based on 100% of production values (i.e., current level of production) as total quota are 0.109 in the basic scenario 1, 0.112 in the seasonal closure scenario, and 0.117 in the upper bounds scenario. In general, these scenarios have similar paths over quota. Efficiencies in the scenarios of technical inefficiency, lower bounds, and basic scenario 2 are 0.170, 0.174, and 0.180, respectively. Efficiencies of these scenarios are approximately the same at 100% quota, but have somewhat different paths from each other. Basic scenario 2 shows the lowest score at 100% of quota among all scenarios, but is getting close to the most efficient path of basic scenario 1 with a decrease in quota. The path of the technical inefficiency scenario changes more smoothly and becomes more inefficient than that of basic scenario 2 as the quota drops. The path of the lower bounds scenario is almost stationary when less than 60% of quota is applied, and the efficiency is 0.100 at 36% of quota.

Second, Figure 5 shows capacity outputs of computed product quantities based on each scenario. The results show efficiencies at 100% quota are 0.078 in the basic scenario 1, 0.079 in the seasonal closure scenario, and 0.083 in the upper bounds scenario. These scenarios are relatively efficient and similar to those of the production value. Scenarios of technical inefficiency and basic scenario 2 are different and they are 0.102 and 0.132 at 100% quota, respectively. But, they have similar paths of capacity outputs as total quota becomes restricted. In the lower bounds scenario, the efficiency is 0.150 at 100% quota, and this scenario has the most inefficient score among all the scenarios.

(c) TAC species

We show results of sensitive analyses by only imposing quota on all TAC species. First, Figure 6 shows the result where the total product quantities are separated into two variables of all TAC species and Non-TAC species. Efficiencies of each scenario are somewhat different at 100% TAC quota level. That is, the efficiencies are 0.117 in the basic scenario 1, 0.124 in the seasonal closure, 0.130 in the upper bounds, 0.143 in the technical inefficiency, 0.174 in the basic scenario 2, and 0.183 in the lower bounds. In addition, the paths of each scenario curve alongside each other and are approximately parallel.

Second, Figure 7 shows the result using data that the total product quantities are divided into three variables: TAC species, other fish and other marine animals. The efficiencies of each scenario are a little different from each other at 100% quota, and have similar lines as decreasing the quota, likewise the result of the two variables above. Efficiencies at 100% quota are, in descending order of efficiency, 0.147 in the basic scenario 1, 0.156 in the seasonal closure, 0.162 in the upper bounds, 0.175 in the technical inefficiency, 0.187 in the basic scenario 2 and 0.207 in the lower bounds.

Then, we provide the results that only impose quota on each of six TAC species. First, Figure 8 shows the result using two variables, 1) the six TAC species and 2) one other, into which the estimated product quantities are divided. At 100% TAC quota efficiencies in the scenarios of Japanese sardine, Japanese jack mackerel and Mackerel are 0.089, 0.096 and 0.097, respectively, and the efficiency paths of these species scenarios vary slightly as each TAC quota decreases. At 100% TAC quota efficiencies in the scenarios of Pacific saury, Alaska Pollock and Japanese common squid are 0.102, 0.103, and 0.107, respectively. The efficiency paths vary more than the results of the others as each TAC quota decreases. The efficiency of the Queen crab scenario is 0.089 at 100% TAC quota, and the efficiency path shows the highest path among all the scenarios.

In contrast, the efficiency of basic scenario 1, imposing quota on total quantities of all TAC species, is 0.117 at the quota of current industry level. The score is the most inefficient among all the scenarios. This suggests that there are fewer options to choose activity vectors of the aggregated entities to satisfy quota of each TAC species. In this case, quota is imposed only on a certain TAC species and, therefore, the other fishery quantities have capacities to catch 100% of current outputs. Therefore, options to choose fixed input factors given that quota imposing on TAC species are fewer and the efficiency paths change more horizontally.

Second, Figure 9 shows the results using each of six TAC species, other fish, and other marine animals. Efficiencies at 100% quota are 0.113 in the Japanese sardine scenario, 0.117 in the

Japanese jack mackerel scenario, 0.119 in the Mackerel scenario, 0.127 in the Pacific saury scenario, 0.122 in the Alaska Pollock scenario, 0.113 in the Queen crab scenario, 0.147 in the Japanese common squid scenario, and 0.147 in the all TAC species scenario. The efficiency paths of the Japanese Sardine and Queen crab scenarios are the most inefficient paths, and that of the all TAC species scenario is the most inefficient, likewise the path using two variables above. The scenarios of each TAC species, except Mackerel and Alaska Pollock, are nearly parallel to the horizontal line at less than 95% of each quota. The scenarios of Mackerel and Alaska are nearly parallel at less than 70% and 50% quotas, respectively.

These varied efficiencies depend on the selection of outputs. When each output in each category is separated in different model, the efficiency score will become even lower. It is difficult to measure the efficiencies of each fishery method because there are many fishery species in the Japanese sea and many fishery methods developed in the same regions. While we can estimate efficiencies in various detailed cases using more disaggregated categories, it will become difficult to discuss entire fisheries in Japan. The opposite is also true. Based on the results, the efficiency paths are approximately the same among the cases, which vary only in quotas of each TAC species.

In summary, ensuring the current capacity outputs, except of certain TAC species, the fixed inputs can satisfy the capacity outputs for the TAC species. Regarding the capacity outputs per fishery area, the most efficient areas are the Japan Sea in the north of basic scenario 1 and the Pacific Ocean in the south of basic scenario 2 (see Table A6 in Appendix). Most areas have excess capacities of more than 100% in basic scenario 2. This implies that there are fixed inputs, which can produce more than twice of the current quantities in Japan.

The most efficient fishery, where we define fish with the lowest excess capacity, is Pacific Saury. There are excess capacities of 48.0% and 47.8% on Pacific Saury using the two and three variables divided above (fishery type 1). The most inefficient fishery is for Japanese common squid. There are excess capacities of 199.1% and 193.0%.

5.2. Reducing the Number of Fishery Entities

We compute the amount of non-zero activity vectors from the results above and provide the optimal numbers of the aggregated fishery entities per Japanese sea area (Table A7 in Appendix). Among all the scenarios, except the lower bounds scenarios, the optimal total number of fishery entities, using the quantities data of 7,483 entities in our sample, are as follows; 1). 1,257 at a minimum in the technically tolerated inefficiency scenario using one variable output, 2). 2,650 at a maximum in the upper bounds scenario using the three variable outputs.

On average the optimal total DMU numbers are about 2,000. The values of the activity vectors are almost at upper limits among all the scenarios (i.e., all inputs are utilized). One exception is that the total of the lower bounds scenario is 7,483. We compute the numbers of fishery entities by multiplying the active vector values and the numbers of entities in each aggregated entity level. The minimum number is 5,704 in the basic scenario 1. Here we use the quantities data of two variable outputs - Japanese sardine and other. The maximum number is 18,998 in the lower bounds scenario using the production value data of one variable output.

We notice there are large differences among the optimal sizes of fishery entities in each scenario. On average, however, the optimal size of the current Japanese fisheries is about one third of current size. In other words, one third of the current fishery entities are required even if the central government implements fishery policies in the most efficient way.

5.3. The Optimal Input Levels

We compute the optimal amounts of inputs in each scenario (see Table A8 in Appendix for detail). These values are computed in the same manner as in section 4 to interpret the fixed inputs easily.

First, in the basic scenario 1 and 2, optimal input values of gross registered tons and horse powers (kilowatt) are significantly smaller than optimal total fixed inputs as flow variables. In the basic scenario 1 using the production value data, the optimal aggregated size is 10.85% of the current fixed inputs. In the disaggregated data, these are 98.84% of the current average fishing days on board, 1.76% of the current gross registered tons, and 1.51% of the horse powers.

In the seasonal closure scenarios, the optimal average fishing days are smaller than those in the basic scenarios. However, the gross registered tons and horse powers are larger than those in the basic scenarios. Using the production value data, the optimal sizes are 10.85% of the current fixed inputs in the aggregate level. The disaggregated result shows these are 98.84% of the current average fishing days, 1.76% of the current gross registered tons, and 1.51% of the horse powers. Therefore, it is effective to reduce the fixed factor inputs rather than the fishing days. The fishery entities enlarge the fixed inputs to deal with the seasonal closure. This shows that seasonal closure policies may not contribute to capacity reduction.

In the technical inefficiency scenarios, the four inputs (of gross registered tons, horse powers, optimal fishing days and labor power) are used more than in the basic scenario 1. In these scenarios using the production value data, the optimal sizes are 17.00% of the current fixed inputs, and the disaggregated results show values of 105.34% of the current average fishing days, 3.73% of the current gross registered tons, and 3.27% of the horse powers. The optimal average fishing days are average values of DMUs with non zero activity vectors and, therefore, more than 100% of the average fishing days are in attendance on average.

In the upper bounds scenarios, results are similar to the seasonal closure scenarios. That is, while the optimal average fishing days are smaller than those in the basic scenarios, the gross registered tons and horse powers are larger than those in the basic scenarios. These imply that when 10% of the aggregated entities' activities are constrained, the aggregated entities will fish on the upper limit days and enlarge the fixed inputs compared with the basic scenario 1.

Going through the amounts of the optimal inputs in each fishery type, we see that allocating the fishery types in the most efficient way is different over specific fishery types (see Table A9 in Appendix). In addition, a fishery type with a large amount of optimal inputs may not be an efficient method itself, but a method with large capacity outputs from optimal inputs based on the first step revised industry model. Relatively large amounts are types of surrounding nets (4), Lift nets (6), Fixed nets (7) among others, and Long lines (9) especially are utilized little.

5.4. Estimates of Cost Reduction

We compute the fishery expenditures of each scenario in Table 3. Overall, required costs of vessels, fishing gears and oils (in our computed cases) are less than about 5 percent of current costs, and the wages and total costs are about 30 and 20 percent, respectively, except the lower bounds scenarios. In the basic scenario 1, using one output variable of the production value, what we need as costs of vessels, fishing gears, oil, wages and total are 1.71%, 1.76%, 1.22%, 30.97%, and 20.78%, respectively. The reduction in total number of fishing vessels represents a large amount of reduction in total cost in the long run. These significant potential results are important for policy purpose.

In the lower bounds scenarios, the optimal costs of vessel, fishing gears and oils are more than 100% of the current costs. In addition, costs of oil, wages and total are about 15%, 20% and 50% of current costs, respectively. The total fishery expenditures in the seasonal closure scenarios and the upper bounds scenarios are smaller than in the basic scenarios. This is because the necessary average fishing days and labor powers in the two scenarios are fewer than those in the basic scenarios 1.

6. Discussion and Conclusion

Global harvest peaked in about 1990 with the expansion of the fisheries to new regions. Because there were no frontiers left to exploit, however, it declined after that (Andrew et al., 2002). Macinko and Bromley (2002) argue the ITQ system is not a sufficient policy instrument to prevent overfishing, instead providing individually specific catch shares of the TAC to each fisherman is the key to avoid the race for fish. Thus, moving idea into practice with actual implementation of catch shares, it is crucial to estimate the potential of cost reduction in the fishery industry assuming ideal individually specific catch shares of the TAC is possible. This study analyzes the potential calculation when a country decides to curb overfishing in the industry.

In Japan, the maximum level of production the fixed inputs are capable of supporting (i.e., capacity output) could be more than three times larger. Additionally, current overall fixed inputs could be reduced to one-tenth. Furthermore, central government plans could reduce to one-third fishery entities maintaining the capacity output to ensure the total fishery catch. Getting rid of these inefficient fishers would help lead to sustainable fishery management. Furthermore, a government-backed industry development program would need this type of change.

If the community can invest in adaptive governance of this allocation, we may move toward a more sustainable path. The major weakness in our analysis is the assumption that marine resources are fixed in the data we have. Of course, the resource stock changes over time and, therefore, the computed outcome would be changed. We do not claim our computed inputs should remain the same over time. Instead, this study urges that policy makers adopt a learning process by suggesting the use of subsidies to adjust the input use (or other methods) by adaptive management rather than imposing current freely accessible solutions.

Furthermore, we do not imply that government needs to control the decision making of all the fishermen as in a central controlled economy. Instead, fishery resource is a public asset managed by public policy, just as a host of other natural resource-based public assets is managed by public agencies (Macinko and Bromley, 2002). Therefore, we believe our results have an implication on public policy.

We need to note, in addition, the scenario analyses in this study assume that the status-quo fishing activity management system is run by the central planners. Ideally, the efficiencies in fisheries are necessary to be estimated based not only on the current management system run by the central planners, but also other mechanisms such as ITQ. Even with these problems, we believe this paper will provide important implications for policy design in Japan. These results are much larger than the potential of Denmark as reported in studies by Kerstens et al. (2006). These differences are caused by the large divergence of fishery management level (or efficiency). In perfect competition, many of these inefficient fishermen are not able to survive in the market. The subsidies are thought to be the reason they are able to exist. Our study shows that even Japan utilizes the subsidies in the fisheries and our optimal management is shown to be more cost effective. In addition, suppose we apply the reduced money to support the fishermen who are not able to survive in the market Significant sums of money are available and therefore this is not a problem.

This study does not discuss both input and output control. Political factors are often in favor of input-oriented approaches to managing fishery. However, there appears to be increasing acceptance of output-oriented controls to manage catches of target fishes (Holland, 2007). Though our approach is not a market-based approach, we try to show the expected outcome using output-oriented controls. For the output-oriented controls be worked inexpensively, improvements in remote automated monitoring technology need to increase the feasibility and then diminish the cost of outcome-control.

Bibliography

Andrew N.L., Agatsuma, Y., Ballesteros, E., Bazhin, A.G. et al. (2002). "Status and management of world sea urchin fisheries." Oceanography and Marine Biology: An Annual Review 2002, 40: 343-425.

Costello, C., S.D. Gaines, and J. Lynham (2008). "Can catch shares prevent fisheries collapse?" Science 321: 1678-81.

Dervaux, B., Kerstens, K., and Leleu, H. (2000). "Remedying excess capacities in French surgery units by industry reallocations: the scope for short and long term improvements in plant capacity utilization." In J. Blank (ed.). (2000). "Public Provision and Performance: Contribution from Efficiency and Productivity Measurement." Amsterdam: Elsevier: 121–46.

Dupont, D. P., Grafton, R. Q., and Kirkley, J. E. (2002). "Capacity utilization measures and excess capacity in multi-product privatized fisheries," Resource and Energy Economics 24: 193-210.

Färe, R., Grosskopf, S., Kerstens, K., Kirkley, J. and Squires, D. (2001). Assessing shortrun and medium-run fishing capacity at the industry level and its reallocation. In R. S. Johnston, and A.L. Shriver (eds), Microbehavior and Macroresults: Proceedings of the Tenth Biennial Conference of the International Institute of Fisheries Economics and Trade. 10–14, July 2000, Corvallis, Oregon, USA, Corvallis: International Institute of Fisheries Economics and Trade.

Färe, R., Grosskopf, S. and Lovell, C. A. K. (1994). "Production Frontiers," Cambridge: Cambridge University Press.

FAO of the United Nations, FishStat Plus, Fisheries and Aquaculture Information and Statistics Service, Global Aquaculture Production, 1950–2005 (Rome: FAO, 2008), http://www.fao.org/fishery/topic/16073 (accessed 8 April 2008).

Gordon, H. S. (1954). "The economic theory of a common property resource: the fishery." Journal of political economy 62: 124-142.

Holland, D.S. (2007) "Managing environmental impacts of fishing: input controls versus outcome-oriented approaches," International Journal of Global Environmental Issues, 7. 2/3: 255–272.

Johansen, L. (1968) "Production functions and the concept of capacity", Namur, Recherches Re´centes sur la Fonction de Production, Collection 'Economie Mathe´matique et Econometrie', n8. ".

Kerstens, K., Vestergaard, N. and Squires, D. (2006) "A Short-Run Johansen Industry Model for Common-Pool Resources: Planning a Fisheries' Industry Capacity to Curb Overfishing," European Review of Agricultural Economics, Vol. 33(3): 361-89.

Kirkley, J. E., Squires, D., Alam, M. F., and Ishak, H. O. (2003). “Capacity and offshore fisheries development: the Malaysian purse seine fishery,” In Pascoe, S., and Gréboval, D. (ed.) (2003). “Measuring capacity in fisheries.” FAO Fisheries Technical Paper 445.

Macinko, S. and D.W. Bromley (2002). “Who owns America's fisheries? Covello, California: Center for. Resource Economics.” Island Press.

Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF). (2008). Japan’s Concept of Individual Transferable Quotas, Ministry of Agriculture, Forestry and Fisheries of Japan, Tokyo. < http://www.jfa.maff.go.jp/suisin/yuusiki/dai5kai/siryo_18.pdf >

Morrison, C. (1985). “Primal and dual capacity utilization: An application to productivity measurement in the U.S. automobile industry.” Journal of Business and Economic Statistics 3: 312–324.

Nelson, R. (1989). “On the measurement of capacity utilization.” Journal of Industrial Economics 37: 273–286.

Peters, W. (1985). “Can inefficient public production promote welfare?” Journal of Economics 45: 395–407.

Vestergaard, N., Squires, D. and Kirkley, J. E. (2003) “Measuring capacity and capacity utilization in fisheries: the case of the Danish Gill-net fleet.” Fisheries Research 60(2-3): 357-68.

Worm B, Barbier E.B., Beaumont N., Duffy J.E., Folke C., Halpern B.S., Jackson J.B.C., Lotze H.K., Micheli F.,. Palumbi S.R., Sala E., Selkoe K., Stachowicz J.J., Watson R. (2006). “Impacts of biodiversity loss on ocean ecosystem services.” Science 314:787-790.

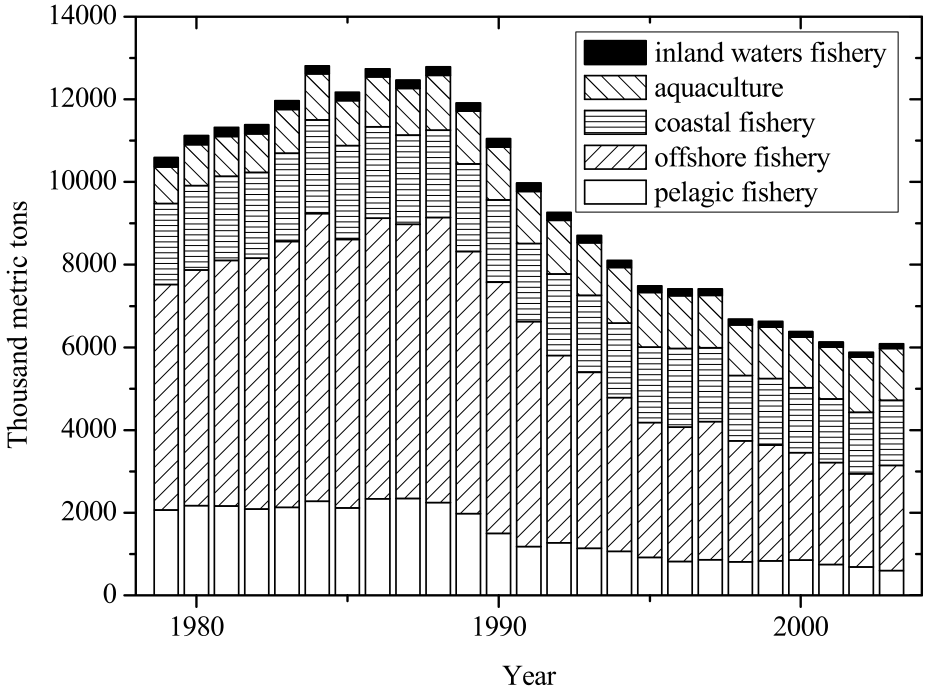

Fig.1 Trend of Fishery Catch in Japan

Source: Ministry of Agriculture, Forestry and Fisheries of Japan, 2003, "*Annual Statistics of Fishery and Fish Culture 2003*"

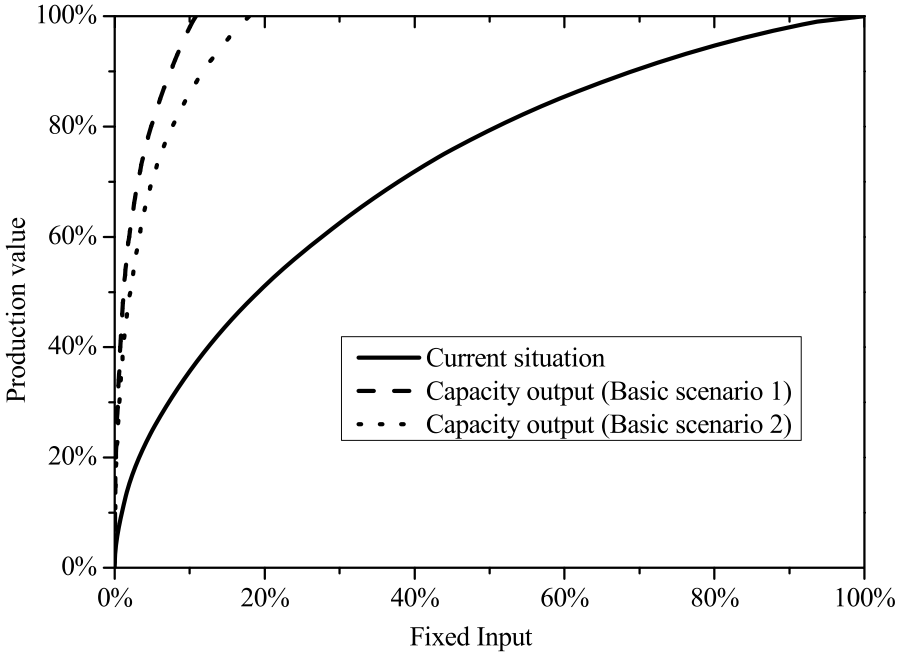

Fig.2. Current and Capacity Output (Catch value)

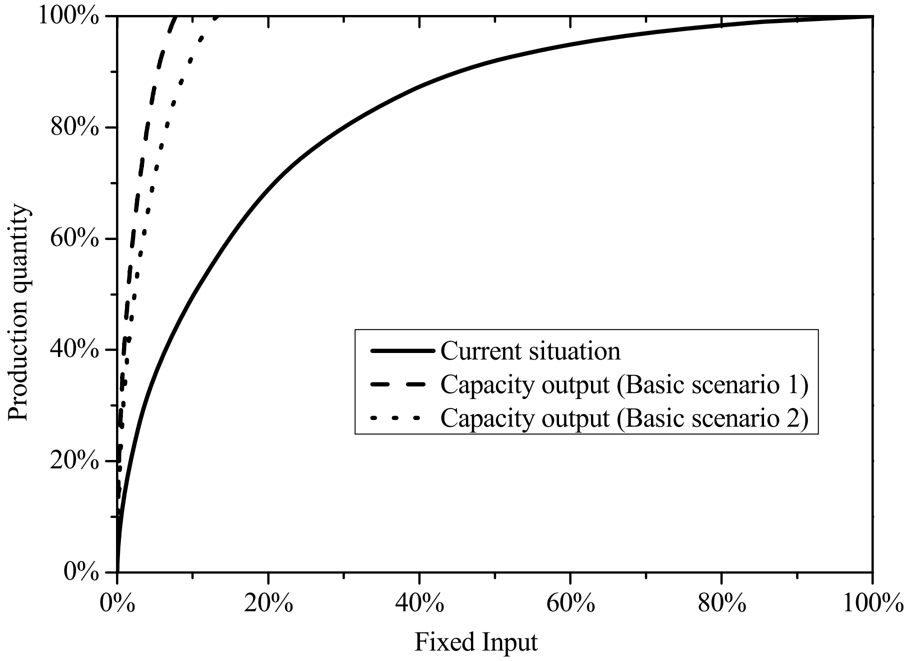

Fig.3. Current and Capacity Output (Catch quantity)

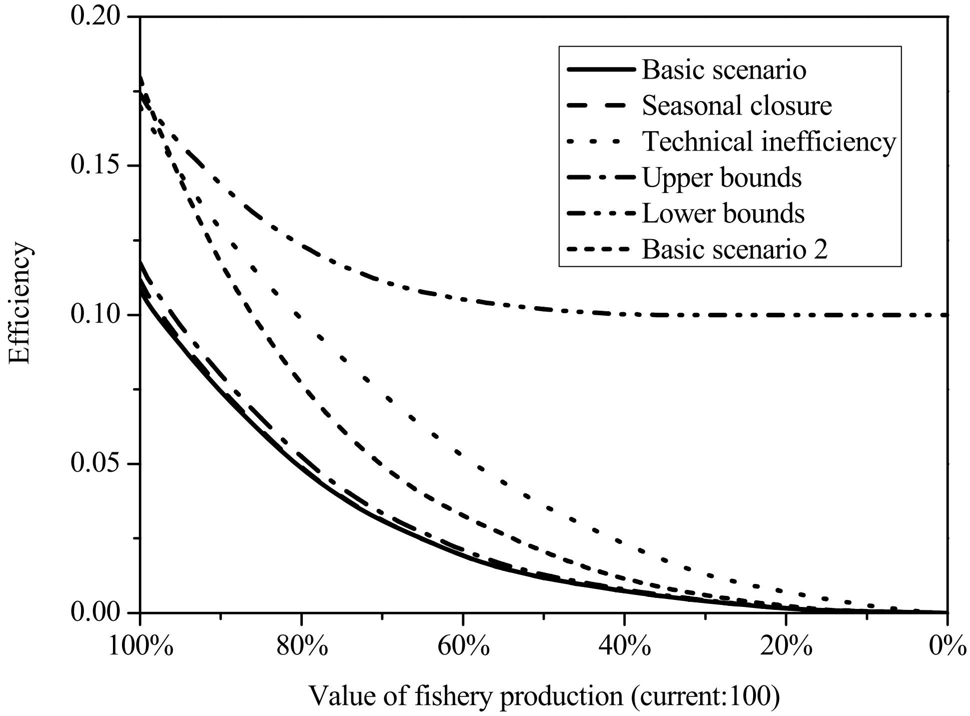

Fig.4. Efficiency Level of Japan's Fishery:

Catch Value of Output using Industry Model

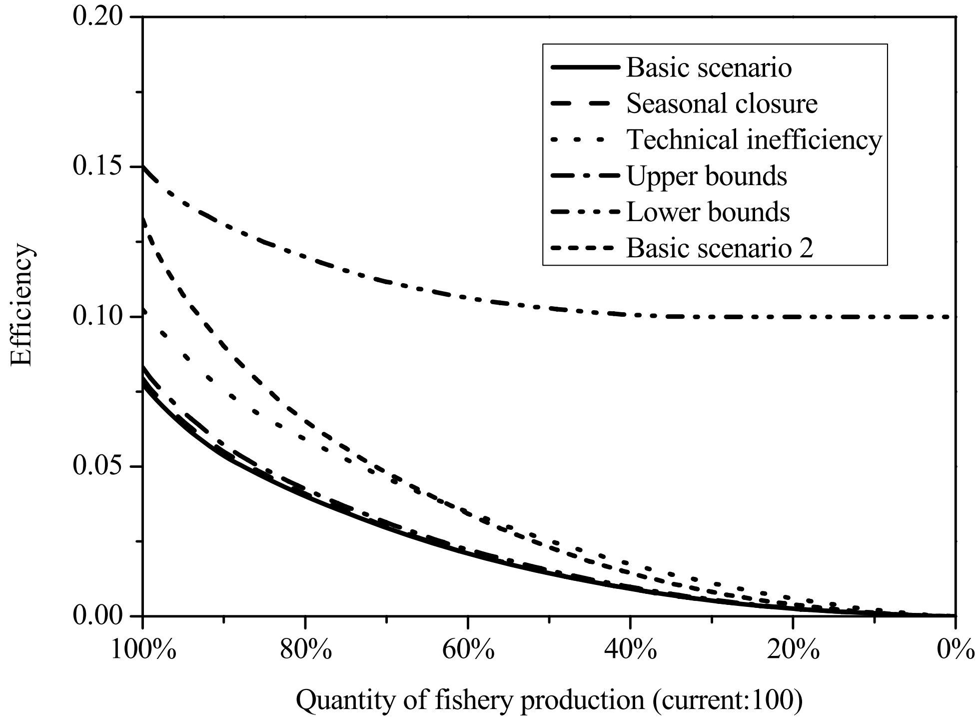

Fig.5. Efficiency Level of Japan's Fishery:
Catch Quantity of Output using Industry Model

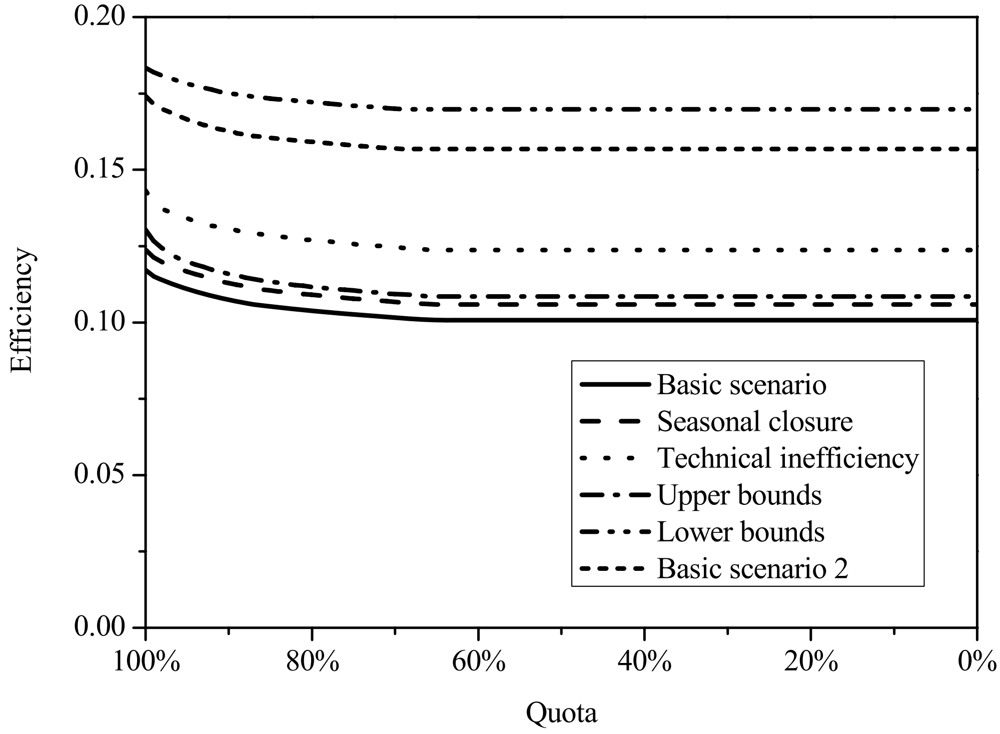

Fig.6. Efficiency Level (Two Outputs Case: TAC and Non-TAC)

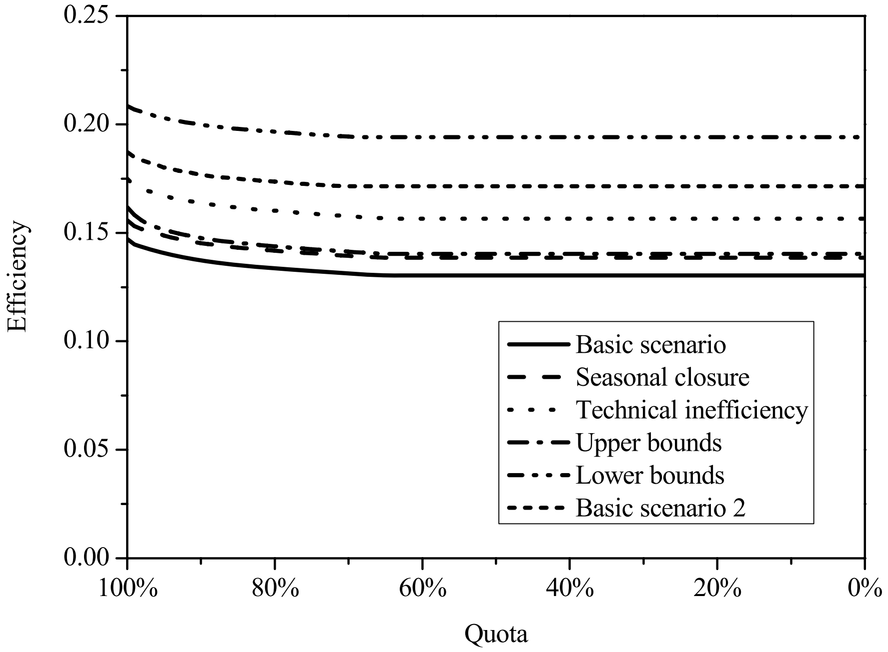

Fig.7. Efficiency Level (Three Outputs Case: TAC and other fish, other marine animals)

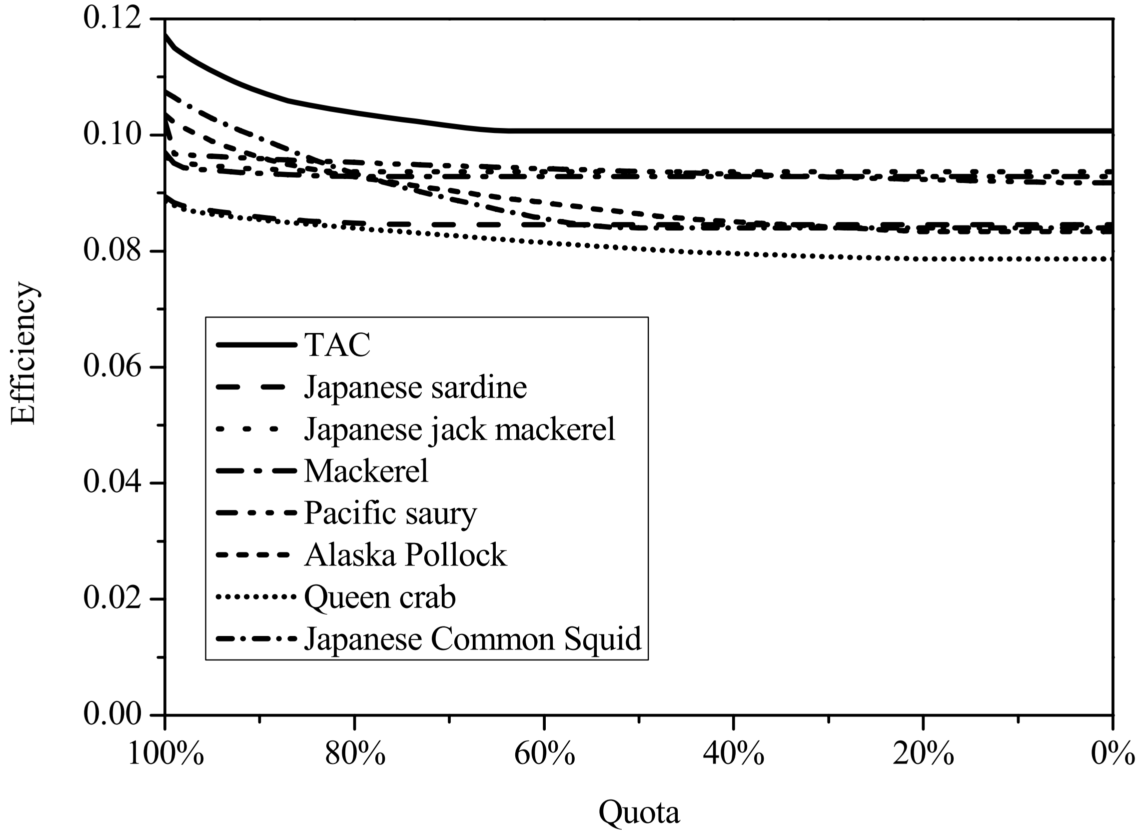

Fig.8. Efficiency Level (Two Outputs Case: Basic scenario 1)

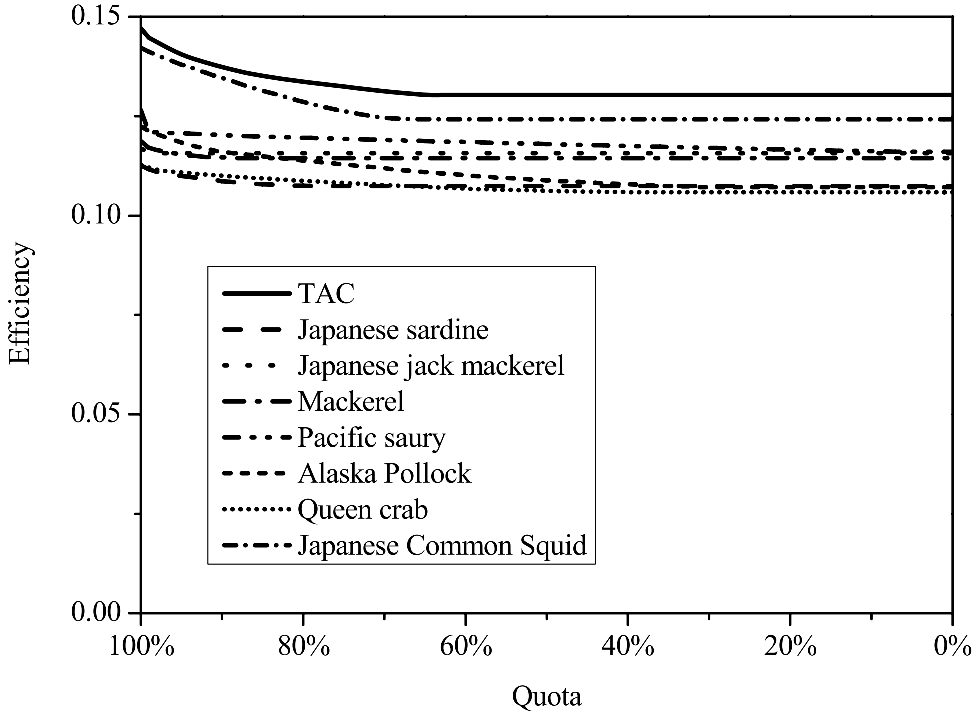

Fig.9. Efficiency Level (Three Outputs Case: Basic scenario 1)

Table 1. Technology (marine fishery)

Fishery type 1	Large classification	Small classification (39 types of fishery): Fishery type 2
1	Trawls	(1) Distant water trawls, (2) Large trawls in East China sea, Off-shore trawl ((3) one-boat operation, (4) two-boats operation), Small trawl ((5) "Teguri" type 1, (6) other kind of "Teguri", (7) Small sail trawl)
2	Boat seine	(8) Drag net, (9) Pulling net
3	Beach seine	(10) Beach seine
4	Surrounding nets	Large and medium surrounding net ((11) One-boat operation (skipjack and tuna on distant water), (12) One-boat operation (skipjack and tuna on off-shore water), (13) Other than skipjack and tuna, one-boat operation), (14) Two-boats operation, Purse seine ((15) One-boat operation, (16) Two-boats operation, (17) Other surrounding nets)
5	Gill nets	(18) Salmon drift gill net, (19) Billfish drift gill net, (20) Other gill nets
6	Lift nets	(21) Saury stick-held dip net, (22) Other lift nets
7	Fixed net	(23) Large set net, (24) Salmon set net, (25) Small set net
8	Other nets	(26) Other nets
9	Long lines	(27) Tuna long line on distant water, (28) Tuna long line on off-shore water, (29) Tuna long line on coastal water, (30) Other long lines
10	Anglings	(31) Skipjack pole-and-line on district water, (32) Skipjack pole-and-line on off-shore water, (33) Skipjack pole-and-line on coastal water, (34) Squid angling on distant water, (35) Squid angling on off-shore water, (36) Squid angling on coastal water, (37) Mackerel angling, (38) Trolling line fishery, (39) Other anglings

Table 2. Scenario Options

Scenario	Constraints of formulation (17) involved
Basic Scenario 1 and 2	$FD_{max} = 365$; $\alpha = 0$; $UB = 1$; $LB = 0$; $0 \le Q \le 1$;
Seasonal closure	$FD_{max} = 200$; $\alpha = 0$; $UB = 1$; $LB = 0$; $0 \le Q \le 1$;
Tolerating technical inefficiency	$FD_{max} = 365$; $\alpha = 0.1$; $UB = 1$; $LB = 0$; $0 \le Q \le 1$;
Upper bounds	$FD_{max} = 365$; $\alpha = 0$; $UB = 0.9$; $LB = 0$; $0 \le Q \le 1$;
Lower bounds	$FD_{max} = 365$; $\alpha = 0$; $UB = 1$; $LB = 0.1$; $0 \le Q \le 1$;
Basic Scenario 2	$FD_{max} = 365$; $\alpha = 0$; $UB = 1$; $LB = 0$; $0 \le Q \le 1$;

Table 3. Computed Fishery Expenditures of Each Scenario

	Costs Vessels	Fishing gears	Oil	Wages	Total
Current situation (unit: billions of yen)	75.48	29.32	91.88	372.45	569.09
1 output; Production value					
Basic scenario (10 fishing methods)	1.71%	1.76%	1.22%	30.97%	20.78%
Seasonal closure	3.00%	3.29%	1.42%	29.42%	20.05%
Technical inefficiency	3.63%	3.73%	2.94%	43.86%	29.86%
Upper bounds	2.43%	2.52%	1.57%	28.20%	19.16%
Lower bounds	171.29%	170.48%	17.41%	24.31%	50.22%
Basic scenario 2 (39 fishing methods)	3.76%	3.81%	3.28%	42.35%	28.94%
1 output; Production quantity					
Basic scenario (10 fishing methods)	0.79%	0.82%	0.61%	26.43%	17.54%
Seasonal closure	2.15%	2.37%	0.72%	25.55%	17.24%
Technical inefficiency	1.88%	2.00%	1.10%	23.72%	16.05%
Upper bounds	1.63%	1.74%	0.81%	23.81%	16.02%
Lower bounds	153.39%	152.94%	15.00%	20.89%	44.32%
Basic scenario 2 (39 fishing methods)	2.68%	2.73%	1.82%	32.82%	22.27%
2 outputs; TAC and other species					
Basic scenario (10 fishing methods)	1.78%	1.85%	1.40%	34.14%	22.90%
Seasonal closure	4.06%	4.47%	1.76%	32.15%	22.10%
Technical inefficiency	2.80%	2.92%	2.08%	35.15%	23.86%
Upper bounds	3.82%	3.85%	1.92%	31.87%	21.87%
Lower bounds	177.69%	176.90%	18.33%	29.39%	54.88%
Basic scenario 2 (39 fishing methods)	4.52%	4.52%	3.08%	39.16%	26.95%
2 outputs; Each species and other species					
Japanese sardine	1.78%	1.86%	0.87%	23.49%	15.84%
Japanese jack mackerel	1.25%	1.31%	0.94%	26.82%	17.94%
Mackerel	1.33%	1.38%	0.98%	25.78%	17.28%
Pacific saury	1.61%	1.68%	1.08%	32.35%	21.65%
Alaska Pollock	1.72%	1.82%	1.15%	30.68%	20.59%
Queen crab	1.55%	1.64%	0.83%	26.63%	17.85%
Japanese Common Squid	1.85%	1.96%	1.21%	27.02%	18.23%
3 outputs; TAC, other fish and other marine animals					
Basic scenario (10 fishing methods)	3.44%	3.63%	2.25%	38.07%	25.92%
Seasonal closure	5.23%	5.58%	2.81%	34.70%	24.14%
Technical inefficiency	7.63%	8.30%	3.19%	40.28%	28.31%
Upper bounds	5.75%	6.05%	3.04%	35.20%	24.60%
Lower bounds	193.00%	192.63%	20.85%	33.66%	60.92%
Basic scenario 2 (39 fishing methods)	4.67%	4.82%	3.56%	41.79%	28.79%
3 outputs; Each species, other fish and other marine animals					

Japanese sardine	2.54%	2.71%	1.39%	28.20%	19.16%
Japanese jack mackerel	2.56%	2.73%	1.49%	30.47%	20.66%
Mackerel	2.65%	2.80%	1.51%	29.42%	19.99%
Pacific saury	3.08%	3.29%	1.73%	34.46%	23.41%
Alaska Pollock	4.12%	4.52%	1.65%	32.62%	22.39%
Queen crab	2.31%	2.46%	1.39%	27.69%	18.78%
Japanese Common Squid	18.94%	21.73%	2.14%	34.90%	26.82%

Appendix

Table A1. Descriptive Statistics

	Total	Sample Mean	Sample Variance	Median	Minimum	Maximum	Standard Deviation
Production value (Millions of Yen)	932176.11	124.57	368548.18	20.80	0.01	25894.30	607.08
# of Management entities	74722	9.99	245.96	5.00	1.00	358.00	15.68
Fishing days (average)	-	164.06	4179.12	158.00	1.00	365.00	64.65
# of Fishermen	169800	22.69	2213.11	11.00	1.00	1894.05	47.04
Powered vessels							
Number	77395	10.47	256.93	5.00	1.00	365.00	16.03
Tonnage (GRT)	722019.38	97.94	347865.53	23.95	0.10	30511.00	589.80
Horsepower (kilowatt)	5037164.95	675.45	2055318.90	255.99	2.20	39599.50	1433.64
Production quantity (Thousands of metric tons)- Total	4018.17	0.55	8569.14	0.05	0.00	110.50	2.93
Japanese sardine	48.59	0.01	10.58	0.00	0.00	3.96	0.10
Japanese jack mackerel	217.40	0.03	126.11	0.00	0.00	12.85	0.36
Mackerel	296.02	0.04	287.34	0.00	0.00	20.10	0.54
Pacific saury	264.66	0.04	582.53	0.00	0.00	40.58	0.76
Alaska Pollock	212.60	0.03	162.27	0.00	0.00	24.63	0.40
Queen crab	5.15	0.00	0.15	0.00	0.00	0.74	0.01
Japanese Common Squid	250.93	0.03	113.69	0.00	0.00	20.42	0.34
TAC (a total of above 7 species)	1295.36	0.17	1992.74	0.01	0.00	40.58	1.41

Source: Ministry of Agriculture, Forestry and Fisheries of Japan, 2003, "*the 11th Fishery Census of Japan on 2003*". Ministry of Agriculture, Forestry and Fisheries of Japan, 2003, "*Annual Statistics of Fishery and Fish Culture 2003*"

Table A2. Catch value and number of DMU classified by the fishery type and sea area

		Fishery type										Total
Area		1	2	3	4	5	6	7	8	9	10	
Hokkaido Pacific Ocean, North	# of DMUs	40	-	-	1	66	13	91	-	38	45	294
	# of Management entities	504	-	-	1	1199	102	637	-	259	234	2936
	Production Value	23.8	-	-	1.5	21.1	12.1	26.5	-	6.5	7.7	99.2
Pacific Ocean, North	# of DMUs	67	49	-	11	119	33	105	-	58	111	553
	# of Management entities	494	429	-	29	1500	80	447	-	269	1003	4251
	Production Value	20.4	5.8	-	21.3	5.9	6.3	17.9	-	58.5	19.2	155.2
Pacific Ocean, Middle	# of DMUs	91	67	8	35	214	17	138	26	72	325	993
	# of Management entities	1312	607	31	67	2806	43	458	184	382	3707	9597
	Production Value											

		14.6	17.6	0.1	44.0	9.6	3.0	11.2	0.7	37.4	27.4	165.5
Pacific Ocean, South	# of DMUs	52	48	1	52	130	18	105	16	139	310	871
	# of Management entities	383	205	1	209	1398	120	322	79	850	4977	8544
	Production Value	4.5	3.6	0.2	14.6	2.6	0.5	5.6	0.2	35.7	29.1	96.6
Hokkaido Japan Sea, North	# of DMUs	32	-	-	1	49	11	73	2	23	45	236
	# of Management entities	204	-	-	2	700	44	561	2	172	395	2080
	Production Value	42.6	-	-	0.0	7.9	0.3	11.2	0.1	7.6	6.8	76.6
Japan Sea, North	# of DMUs	62	17	3	1	121	7	96	-	39	115	461
	# of Management entities	329	37	4	1	1850	19	697	-	127	890	3954
	Production Value	5.9	0.3	0.0	1.9	4.5	1.0	11.4	-	5.2	4.7	34.8
Japan Sea, West	# of DMUs	92	32	5	17	110	6	124	2	37	225	650
	# of Management entities	640	88	11	31	1670	20	462	18	256	2770	5966
	Production Value	26.7	0.3	0.1	14.7	4.6	0.2	12.3	0.1	1.1	13.3	73.5
East China Sea	# of DMUs	135	115	4	69	384	57	271	38	199	716	1988
	# of Management entities	1340	669	14	178	4294	265	812	103	1468	11686	20829
	Production Value	9.9	7.5	0.1	41.4	13.3	2.6	9.8	0.6	26.7	33.7	145.7
Seto Inland Sea	# of DMUs	327	160	3	17	353	14	142	12	102	307	1437
	# of Management entities	5245	726	6	29	4021	57	612	46	470	5358	16570
	Production Value	32.3	23.7	0.0	4.3	10.6	0.7	2.8	0.3	2.3	8.2	85.1
All areas	# of DMUs	898	488	24	204	1546	176	1145	96	707	2199	7483
	# of Management entities	10451	2761	67	547	19438	750	5008	432	4253	31020	74727
	Production Value	180.8	58.7	0.4	143.7	80.0	26.7	108.6	2.0	180.9	150.2	932.2

*Production value (unit: Billions of Yen)

Source: Ministry of Agriculture, Forestry and Fisheries of Japan, 2003, "*the 11th Fishery Census of Japan on 2003*"

Table A3. Catch value and quantity classified by fishery type

Fishery type 2	Sample Data Production value (Billions of Yen)	Statistical Data Production value	Total production quantity	Fish	Other marine animal	Japanese sardine	Japanese jack mackerel	Mackerel	Pacific saury	Alaska Pollock	Queen crab	Japanese Common Squid
1	7.5	16.8	140.3	59.1	81.1	-	-	-	-	5.9	-	-
2	1.9	2.5	8.5	6.8	1.7	-	0.4	-	-	-	-	0.0
3	50.8	46.7	364.2	314.1	50.2	0.0	0.2	0.0	-	134.8	4.0	32.3
4	11.7	9.9	26.5	20.9	5.6	-	0.5	-	-	3.5	-	3.1
5	29.1	25.3	45.8	34.6	11.2	0.0	0.9	0.1	0.0	1.1	0.9	0.5
6	79.6	88.4	451.3	41.5	409.9	0.0	1.1	0.0	-	0.2	0.0	0.2
7	0.1	0.2	0.2	0.1	0.1	-	-	-	-	-	-	-
8	51.0	46.8	223.1	170.7	52.4	0.4	0.3	0.1	-	-	-	0.0
9	7.7	8.3	20.2	19.4	0.7	0.0	0.2	0.0	-	0.0	0.0	0.0
10	0.4	0.5	1.3	1.3	0.0	0.1	0.3	0.0	-	-	-	0.0
11	37.0	25.6	157.8	157.8	0.0	-	-	-	-	-	-	-
12	7.0	15.7	64.5	64.5	0.0	-	-	-	-	-	-	-
13	52.7	54.8	611.1	596.8	14.3	36.2	117.6	183.9	0.0	-	-	14.3
14	3.1	2.2	56.6	56.4	0.1	1.8	0.0	1.1	-	-	-	0.1
15	32.7	42.6	317.5	316.3	1.3	6.0	73.4	80.7	0.2	-	-	0.7
16	8.3	8.7	83.5	83.4	0.1	2.2	8.3	4.6	0.0	-	-	0.0
17	2.8	3.1	23.6	23.5	0.0	0.7	0.4	0.7	-	-	-	0.0
18	2.5	6.5	9.4	9.4	0.0	-	-	-	-	-	-	-
19	2.3	2.3	6.4	6.4	0.0	-	-	-	-	-	-	-
20	75.1	71.9	183.8	167.5	16.3	0.1	1.3	0.6	3.1	45.5	0.2	5.8
21	21.1	16.5	255.5	255.5	0.0	0.0	-	0.0	255.5	-	-	-
22	5.6	9.3	48.5	46.5	2.0	0.6	2.0	13.0	0.1	-	-	0.1
23	50.7	47.5	236.5	196.8	39.8	2.6	22.2	31.6	5.5	7.6	-	33.4
24	29.3	33.0	215.6	213.9	1.7	0.0	0.0	0.4	0.0	0.3	-	1.6
25	28.7	33.9	152.8	137.1	15.6	1.2	8.2	2.2	0.3	7.0	-	7.7
26	2.0	2.4	11.8	10.9	0.8	0.2	0.0	5.4	-	-	-	-
27	127.0	89.8	136.1	136.1	0.0	-	-	-	-	-	-	-
28	23.8	27.0	56.9	56.9	0.0	-	-	-	-	-	-	-
29	5.1	5.6	9.8	9.8	0.0	-	-	-	-	-	-	-
30	25.0	20.8	44.0	35.2	8.8	-	0.1	0.0	-	13.7	-	0.0
31	21.0	20.3	97.5	97.5	0.0	-	-	-	-	-	-	-
32	14.0	14.9	57.9	57.9	0.0	-	-	-	-	-	-	-
33	3.2	4.2	10.9	10.9	0.0	-	-	-	-	-	-	-
34	8.2	10.4	60.4	0.0	60.4	-	-	-	-	-	-	1.3
35	13.4	13.5	70.8	0.0	70.8	-	-	-	-	-	-	56.7
36	40.4	39.3	114.8	0.0	114.8	-	-	-	-	-	-	96.2
37	0.8	1.0	2.9	2.9	0.0	-	0.0	2.5	-	-	-	-
38	10.3	13.8	30.6	30.5	0.1	-	0.0	0.1	-	-	-	-
39	38.9	33.4	48.1	46.1	2.0	0.0	4.3	2.2	0.0	0.1	-	0.0

Source: Ministry of Agriculture, Forestry and Fisheries of Japan, 2003, "*Annual Statistics of Fishery and Fish Culture 2003*"

Table A4. Production classified by area

	Hokkaido Pacific Ocean, North	Pacific Ocean, North	Pacific Ocean, Middle	Pacific Ocean, South	Hokkaido Japan Sea, North	Japan Sea, North	Japan Sea, West	East China Sea	Seto Inland Sea
Production value (Billions of Yen)	99.2	155.2	165.5	96.6	76.6	34.8	73.5	145.7	85.1
Production quantity (Thousands of metric tons)									
Total	559.7	629.7	680.4	349.2	370.5	118.6	398.0	659.9	314.8
Japanese sardine	0.2	7.9	6.3	6.1	0.2	0.5	7.7	18.3	1.3
Japanese jack mackerel	2.1	29.4	24.7	29.9	1.6	4.6	35.1	84.2	5.8
Mackerel	2.1	43.7	32.2	41.5	0.9	5.0	49.0	116.6	5.0
Pacific saury	147.5	74.9	23.1	0.8	3.0	12.4	1.3	1.2	0.5
Alaska Pollock	46.8	34.8	12.9	4.5	37.2	7.8	47.8	14.7	8.7
Queen crab	1.0	0.8	0.1	0.0	0.9	0.2	1.5	0.1	0.4
Japanese Common Squid	25.7	65.2	10.8	6.1	19.9	15.5	56.0	49.8	1.9
TAC (a total of above 7 species)	225.6	256.7	110.2	89.0	63.7	46.1	198.4	284.8	23.6

Source: Ministry of Agriculture, Forestry and Fisheries of Japan, 2003, "*Annual Statistics of Fishery and Fish Culture 2003*"

Table A5. Fishery expenditure of business entities divided by Fishery income (average 1962 – 2000)

	Mean 1962-2000	The estimated cost	Assumption
Net earnings from fishery	3.6%		
Fishery income	100%	100%	
Fishery expenditure	96.4%		
Wages	36.5%	40.0%	12 thousand yen per person-day
Vessels	7.2%	7.9%	(1.2 million yen per Grt + 0.05 million yen per kw) / 15 (years)
Implements	3.9%	3.1%	(0.6 million yen per Grt) / 15 (years)
Oil	11.6%	9.9%	(100 yen / kw)*fishing days
(Subtotal)	59.1%	60.9%	

Source: Ministry of Agriculture, Forestry and Fisheries of Japan, 2003, "*Annual Statistics of Fishery and Fish Culture 2003*"

Detailed Appendix Tables (A6-A9)

Table A6. Aggregated Vessel Excess Capacity (%) (1, 2 and 3 outputs; Fishery type 1 and 2)

	Areas Hokkaido Pacific Ocean, North	Pacific Ocean, North	Pacific Ocean, Middle	Pacific Ocean, South	Hokkaido Japan Sea, North	Japan Sea, North	Japan Sea, West	East China Sea	Seto Inland Sea	Total
Production value										
(Fishery type 1)	188.3%	100.1%	184.5%	145.6%	237.6%	82.6%	116.9%	444.4%	1340.4%	308.2%
(Fishery type 2)	129.9%	62.4%	150.4%	61.9%	154.8%	62.7%	79.0%	189.1%	365.3%	141.5%
Production quantity										
(Fishery type 1)	170.1%	114.7%	167.5%	165.9%	260.6%	105.2%	125.8%	362.3%	627.3%	229.1%
(Fishery type 2)	108.9%	58.1%	108.8%	55.4%	161.4%	59.8%	63.5%	140.4%	231.8%	110.0%
2 outputs										
(Fishery type 1)										
Japanese sardine	121.5%	38.2%	120.4%	71.8%	151.5%	96.2%	81.2%	99.5%	95.6%	86.0%
Japanese jack mackerel	137.0%	75.3%	170.9%	106.6%	168.0%	88.6%	110.6%	131.1%	234.6%	123.6%
Mackerel	102.2%	46.4%	150.3%	112.5%	195.9%	63.8%	101.4%	116.6%	91.0%	105.7%
Pacific saury	19.5%	94.3%	75.7%	93.0%	20.9%	11.8%	200.2%	289.7%	225.3%	48.0%
Alaska Pollock	58.9%	69.6%	675.5%	128.4%	53.8%	89.9%	53.4%	252.2%	297.4%	121.0%
Queen crab	24.3%	51.3%	339.5%	129.7%	37.9%	86.6%	60.0%	169.7%	1450.3%	175.3%
Japanese Common Squid	52.9%	65.6%	285.0%	103.9%	63.6%	98.1%	84.8%	650.0%	377.8%	199.1%
TAC (a total of above 7 species)	33.4%	69.8%	218.3%	119.2%	60.3%	66.9%	85.0%	222.2%	249.4%	117.9%

Other marine animals (non-TAC species)	181.8%	94.3%	128.7%	141.8%	198.4%	88.1%	117.3%	206.8%	593.7%	196.7%
(Fishery type 2)										
TAC (a total of above 7 species)	29.7%	60.3%	164.1%	54.6%	53.7%	51.2%	58.0%	177.4%	229.6%	91.2%
Other marine animals (non-TAC species)	162.4%	56.5%	98.1%	55.7%	183.8%	65.2%	68.9%	112.4%	232.0%	118.7%
3 outputs										
(Fishery type 1)										
Japanese sardine	118.4%	36.6%	118.5%	70.0%	149.4%	91.5%	80.2%	97.6%	87.9%	84.1%
Japanese jack mackerel	135.3%	72.0%	169.6%	105.9%	165.6%	84.9%	108.3%	129.6%	197.9%	120.8%
Mackerel	74.6%	45.6%	148.8%	108.8%	116.9%	62.9%	98.9%	113.1%	75.0%	102.3%
Pacific saury	19.5%	94.3%	75.6%	92.5%	16.9%	11.8%	199.6%	287.2%	224.8%	47.8%
Alaska Pollock	57.0%	67.8%	673.1%	127.3%	52.7%	88.9%	52.6%	251.8%	293.8%	119.6%
Queen crab	50.8%	59.7%	272.9%	93.5%	60.2%	93.9%	81.0%	639.4%	353.6%	175.0%
Japanese Common Squid	24.3%	51.2%	339.3%	129.6%	37.9%	86.2%	59.6%	169.7%	1448.9%	193.0%
TAC (a total of above 7 species)	32.3%	67.0%	177.0%	70.3%	56.9%	64.5%	69.5%	187.8%	235.5%	99.9%
Other fishes (non-TAC species)	110.5%	85.7%	117.3%	121.9%	153.8%	75.7%	92.3%	142.2%	294.4%	129.4%
Other marine animals (non-TAC species)	369.9%	73.8%	107.5%	110.9%	222.9%	92.4%	83.6%	289.4%	322.6%	224.0%

(Fishery type 2)										
TAC (a total of above 7 species)	29.7%	60.3%	164.1%	54.6%	53.7%	51.2%	58.0%	177.4%	229.6%	91.2%
Other fishes (non-TAC species)	100.5%	55.5%	97.1%	53.9%	145.1%	65.4%	69.5%	96.5%	276.5%	100.6%
Other marine animals (non-TAC species)	358.0%	61.5%	103.8%	85.2%	214.4%	63.7%	63.8%	267.0%	168.0%	184.4%

Table A7. Industry Model Scenarios: Efficiency measure and activity vectors (total and per area)

		All areas	Hokkaido Pacific Ocean, North	Pacific Ocean, North	Pacific Ocean, Middle	Pacific Ocean, South	Hokkaido Japan Sea, North	Japan Sea, North	Japan Sea, West	East China Sea	Seto Inland Sea
Actual	# of DMUs	7483	294	553	993	871	236	461	650	1988	1437
	# of management entities	74727	2936	4251	9597	8544	2080	3954	5966	20829	18764
1 output; Production value											
Basic scenario (10 fishing methods)	Efficiency	0.109									
	# of DMUs	2008	94	255	286	484	21	269	304	263	32
	Mean w_{ja}	0.998	0.998	0.999	0.995	0.998	0.993	0.998	0.997	0.998	0.993
	# of management entities	11527	662	1028	1946	3055	115	1834	1420	1347	120
Seasonal closure (up to 200 days per year)	Efficiency	0.112									
	# of DMUs	2051	94	274	280	501	21	276	310	263	32
	Mean w_{ja}	0.977	0.998	0.945	0.980	0.969	0.993	0.990	0.982	0.998	0.989
	# of management entities	11717	662	1123	1884	3146	115	1860	1469	1342	116
Technical tolerated inefficiency (up to 10 times)	Efficiency	0.170									
	# of DMUs	2501	102	263	392	470	41	259	264	627	83
	Mean w_{ja}	0.998	0.996	0.997	0.999	0.998	0.985	0.998	1.000	0.999	1.000
	# of management entities	16619	802	1169	2749	3302	263	1804	1354	3823	1353
Upper bounds (= 0.9)	Efficiency	0.117									
	# of DMUs	2169	102	284	290	529	23	289	328	286	38

	Mean w_{ja}	0.898	0.892	0.898	0.899	0.900	0.877	0.899	0.899	0.899	0.882
	# of management entities	12152	680	1175	1884	3205	124	1919	1547	1490	128
Lower bounds (= 0.1)	Efficiency	0.174									
	# of DMUs	7483	294	553	993	871	236	461	650	1988	1437
	Mean w_{ja}	0.297	0.324	0.471	0.332	0.536	0.166	0.560	0.459	0.167	0.1
	# of management entities	18998	905	1415	3034	3349	420	1895	1767	3708	2505
Basic scenario 2 (39 kinds of fishing methods)	Efficiency	0.180									
	# of DMUs	2598	92	346	311	624	21	312	326	532	34
	Mean w_{ja}	0.998	0.998	0.999	0.999	1.000	0.973	0.998	0.999	1.000	0.972
	# of management entities	15322	771	1602	2362	3731	119	2227	1767	2615	128
1 output; Production quantity											
Basic scenario (10 fishing methods)	Efficiency	0.078									
	# of DMUs	1473	92	165	238	247	32	144	106	366	83
	Mean w_{ja}	0.997	1.000	0.995	1.000	0.997	0.993	0.996	0.995	0.998	0.998
	# of management entities	6087	659	535	1161	860	152	588	258	1552	322
Seasonal closure (up to 200 days per year)	Efficiency	0.079									
	# of DMUs	1568	92	170	255	268	33	149	140	376	85
	Mean w_{ja}	0.973	1.000	0.969	0.970	0.978	0.989	0.986	0.958	0.967	0.974
	# of management entities	6674	659	554	1347	1008	157	655	368	1588	338
Technical tolerated inefficiency (up to 10 times)	Efficiency	0.102									
	# of DMUs	1257	96	196	183	201	35	142	108	190	106
	Mean w_{ja}	0.996	0.994	0.995	0.998	1.000	0.980	0.998	0.997	0.999	0.993

	# of management entities	6591	718	875	915	748	212	670	264	777	1412
Upper bounds (= 0.9)	Efficiency	0.083									
	# of DMUs	1615	101	183	271	272	34	156	129	382	87
	Mean w_{ja}	0.898	0.895	0.895	0.897	0.900	0.889	0.900	0.898	0.900	0.897
	# of management entities	6825	664	668	1361	1005	155	731	329	1562	350
Lower bounds (= 0.1)	Efficiency	0.150									
	# of DMUs	7483	294	553	993	871	236	461	650	1988	1437
	Mean w_{ja}	0.235	0.341	0.352	0.280	0.294	0.163	0.345	0.242	0.208	0.113
	# of management entities	15422	907	1102	2322	1814	411	880	1125	4153	2563
Basic scenario 2 (39 fishing methods)	Efficiency	0.132									
	# of DMUs	1752	86	223	319	376	24	161	122	342	99
	Mean w_{ja}	0.996	0.993	0.995	0.998	0.997	0.980	0.997	0.995	0.998	0.997
	# of management entities	8393	577	904	1895	1478	117	930	321	1637	534
2 outputs; TAC and others											
Basic scenario (10 fishing methods)	Efficiency	0.117									
	# of DMUs	0.996	73	215	285	364	65	161	105	538	74
	Mean w_{ja}	1880	0.989	0.991	0.998	0.999	0.992	0.993	0.991	0.998	0.997
	# of management entities	8388	438	922	1622	1844	279	757	216	1875	435
Seasonal closure (up to 200 days per year)	Efficiency	0.124									
	# of DMUs	2043	88	227	324	380	79	163	110	591	81
	Mean w_{ja}	0.952	0.972	0.948	0.944	0.970	0.972	0.977	0.948	0.936	0.943
	# of management entities	9232	587	991	1856	1946	329	773	234	2029	487

Technical tolerated	Efficiency	0.143									
inefficiency (up to	# of DMUs	1885	86	223	267	309	70	157	105	320	348
10 times)	Mean w_{ja}	0.995	0.997	0.992	0.999	0.997	0.981	0.993	0.989	0.998	0.997
	# of management entities	9606	563	1060	1662	1630	296	799	234	1080	2282
Upper bounds (=	Efficiency	0.130									
0.9)	# of DMUs	2113	129	232	323	403	96	180	112	550	88
	Mean w_{ja}	0.897	0.894	0.897	0.898	0.899	0.889	0.893	0.893	0.899	0.895
	# of management entities	9620	768	1037	1780	2090	480	874	235	1857	499
Lower bounds (=	Efficiency	0.183									
0.1)	# of DMUs	7483	294	553	993	871	236	461	650	1988	1437
	Mean w_{ja}	0.289	0.282	0.430	0.305	0.419	0.280	0.389	0.215	0.303	0.132
	# of management entities	16865	748	1437	2670	2449	479	1206	1054	4158	2664
Basic scenario 2 (39	Efficiency	0.174									
fishing methods)	# of DMUs	2234	82	250	355	383	72	165	129	701	97
	Mean w_{ja}	0.997	0.984	0.996	0.997	1.000	0.984	0.994	0.993	0.999	0.998
	# of management entities	10838	578	1247	2194	1528	344	974	410	3018	545
2 outputs; each species and others											
Japanese sardine	Efficiency	0.089									
	# of DMUs	1392	102	174	267	224	52	147	113	178	135
	Mean w_{ja}	0.994	0.988	0.994	0.998	0.999	0.967	0.998	0.997	0.992	0.988
	# of management entities	5740	687	626	1465	726	239	668	279	589	461

Japanese jack mackerel	Efficiency	0.096									
	# of DMUs	1537	101	184	265	305	43	137	141	279	82
	Mean w_{ja}	0.997	0.993	0.998	1.000	0.998	0.982	0.996	0.997	0.999	0.983
	# of management entities	6542	686	756	1486	1086	208	736	415	858	311
Mackerel	Efficiency	0.097									
	# of DMUs	1523	103	186	250	326	42	139	141	223	113
	Mean w_{ja}	0.996	0.996	0.994	1.000	0.999	0.962	0.994	0.996	0.999	0.990
	# of management entities	6543	714	757	1433	1202	174	734	402	767	360
Pacific saury	Efficiency	0.102									
	# of DMUs	1852	83	168	256	336	80	135	146	366	282
	Mean w_{ja}	0.996	0.987	0.992	0.998	0.996	0.989	0.992	0.993	1.000	0.999
	# of management entities	8665	589	666	1447	1311	500	724	481	1337	1610
Alaska Pollock	Efficiency	0.103									
	# of DMUs	1902	126	193	240	308	22	172	110	558	173
	Mean w_{ja}	0.996	0.999	0.995	0.997	0.999	0.956	0.992	0.992	0.998	0.996
	# of management entities	8101	887	629	1120	1158	110	905	307	2057	928
Queen crab	Efficiency	0.089									
	# of DMUs	1564	90	182	238	258	23	147	122	421	83
	Mean w_{ja}	0.994	0.985	0.989	0.998	0.997	0.969	0.993	0.990	0.998	0.992
	# of management entities	6604	628	628	1161	928	110	649	369	1802	329
Japanese Common Squid	Efficiency	0.107									
	# of DMUs	1654	117	209	265	256	66	155	176	321	89
	Mean w_{ja}	0.994	0.992	0.996	0.998	0.997	0.975	0.996	0.992	0.996	0.987

	# of management entities	6805	722	886	1493	973	331	650	610	813	327
3 outputs; TAC, other fish and other marine animals											
Basic scenario (10 fishing methods)	Efficiency	0.147									
	# of DMUs	2349	81	234	308	421	71	173	238	678	145
	Mean w_{ja}	0.995	0.983	0.994	0.999	0.997	0.971	0.991	0.998	0.998	0.991
	# of management entities	11252	457	1004	2336	2284	307	935	922	2290	717
Seasonal closure (up to 200 days per year)	Efficiency	0.156									
	# of DMUs	2555	95	246	353	438	80	175	229	789	150
	Mean w_{ja}	0.954	0.959	0.936	0.953	0.966	0.980	0.977	0.958	0.942	0.954
	# of management entities	12119	566	1100	2510	2364	346	886	870	2702	775
Technical tolerated inefficiency (up to 10 times)	Efficiency	0.175									
	# of DMUs	2358	86	241	306	350	68	173	228	500	406
	Mean w_{ja}	0.995	0.989	0.993	0.995	0.997	0.976	0.992	0.995	0.997	0.998
	# of management entities	12680	504	1100	2319	1889	313	933	927	2385	2310
Upper bounds (= 0.9)	Efficiency	0.162									
	# of DMUs	2650	140	247	353	456	99	205	261	727	162
	Mean w_{ja}	0.896	0.887	0.894	0.897	0.898	0.887	0.893	0.895	0.898	0.896
	# of management entities	12650	706	1070	2475	2445	544	1123	1006	2480	801
Lower bounds (= 0.1)	Efficiency	0.207									
	# of DMUs	7483	294	553	993	871	236	461	650	1988	1437

	Mean w_{ja}	0.338	0.319	0.455	0.351	0.498	0.280	0.406	0.398	0.332	0.157
	# of management entities	18954	790	1497	3323	2797	501	1297	1572	4388	2789
Basic scenario 2 (39	Efficiency	0.187									
fishing methods)	# of DMUs	2554	90	253	367	374	76	218	257	676	243
	Mean w_{ja}	0.996	0.975	0.997	0.997	0.998	0.976	0.995	0.994	0.999	0.999
	# of management entities	12665	545	1211	2595	1438	370	1386	1111	2310	1699
3 outputs;											
each species, other											
fish and other											
marine animals											
Japanese sardine	Efficiency	0.113									
	# of DMUs	1720	99	209	338	281	69	157	212	199	156
	Mean w_{ja}	0.994	0.993	0.993	0.996	0.996	0.979	0.992	0.999	0.991	0.991
	# of management entities	7751	701	972	2186	1058	297	684	801	469	583
Japanese jack	Efficiency	0.117									
mackerel	# of DMUs	1864	100	207	354	315	68	152	213	332	123
	Mean w_{ja}	0.992	0.984	0.990	0.997	0.995	0.975	0.992	0.993	0.997	0.981
	# of management entities	8525	656	1017	2344	1185	295	756	790	889	593
Mackerel	Efficiency	0.119									
	# of DMUs	1866	97	198	350	359	61	154	204	284	159
	Mean w_{ja}	0.993	0.984	0.995	0.997	0.996	0.971	0.993	0.995	0.993	0.987
	# of management entities	8381	645	913	2306	1437	240	779	731	720	610
Pacific saury	Efficiency	0.127									

	# of DMUs	2107	86	207	353	330	85	146	208	358	334
	Mean w_{ja}	0.993	0.986	0.985	0.995	0.999	0.977	0.987	0.996	0.996	0.995
	# of management entities	10084	549	1001	2333	1288	543	700	767	1024	1879
Alaska Pollock	Efficiency	0.122									
	# of DMUs	2102	122	230	317	339	29	184	192	466	223
	Mean w_{ja}	0.994	0.985	0.990	0.998	0.994	0.968	0.991	0.988	0.998	0.999
	# of management entities	9649	806	1074	2037	1406	119	970	648	1493	1096
Queen crab	Efficiency	0.113									
	# of DMUs	1785	77	215	330	317	31	160	203	323	129
	Mean w_{ja}	0.993	0.976	0.992	0.997	0.993	0.962	0.991	0.998	0.994	0.992
	# of management entities	7859	439	967	2123	1272	132	689	691	897	649
Japanese Common	Efficiency	0.142									
Squid	# of DMUs	2192	111	233	356	385	62	170	232	518	125
	Mean w_{ja}	0.995	0.990	0.990	0.997	0.997	0.976	0.995	0.995	0.998	0.991
	# of management entities	10377	625	967	2521	1984	326	771	911	1651	621

Table A8. Optimum Input Allocations for Each Scenario

	A (=C*E) Tonnage*Fishing days	B (=D*E) Kilowatt*Fishing days	C Tonnage	D Kilowatt	E Fishing days (average)	Labor	# of vessels
Current situation (100%)	168034144.5	918792136.6	732906.4	5054382.0	164.1	169800	77406
1 output;							
Production value							
Basic scenario 1 (10 fishing methods)	10.85%	10.85%	1.76%	1.51%	98.84%	38.52%	13.58%
Seasonal closure	11.16%	11.16%	3.29%	1.99%	96.09%	38.61%	13.73%
Technical inefficiency	17.00%	17.00%	3.73%	3.27%	105.34%	49.69%	21.75%
Upper bounds	11.73%	11.73%	2.52%	2.10%	89.35%	38.22%	13.71%
Lower bounds	17.41%	17.41%	170.48%	174.11%	29.73%	42.75%	19.60%
Basic scenario 2 (39 fishing methods)	17.95%	17.95%	3.81%	3.57%	102.27%	47.74%	19.01%
1 output;							
production quantity							
Basic scenario 1 (10 fishing methods)	7.76%	7.76%	0.82%	0.69%	102.05%	32.50%	8.53%
Seasonal closure	7.72%	7.93%	2.37%	1.38%	99.27%	33.14%	9.08%
Technical inefficiency	10.24%	10.24%	2.00%	1.46%	111.15%	26.26%	10.52%
Upper bounds	8.31%	8.31%	1.74%	1.24%	92.73%	32.03%	8.92%
Lower bounds	14.80%	15.00%	152.94%	154.98%	23.51%	38.80%	15.66%

Basic scenario 2 (39 fishing methods)	13.25%	13.25%	2.73%	2.49%	105.84%	36.85%	12.43%
2 outputs; TAC and other species							
Basic scenario (10 fishing methods)	11.72%	11.72%	1.85%	1.56%	105.51%	38.01%	12.15%
Seasonal closure	12.38%	12.38%	4.47%	2.62%	99.15%	40.45%	12.94%
Technical inefficiency	14.32%	14.32%	2.92%	2.40%	109.99%	37.82%	14.93%
Upper bounds	13.03%	13.03%	3.85%	3.70%	95.64%	39.52%	12.95%
Lower bounds	18.33%	18.33%	176.90%	180.45%	29.88%	45.21%	18.49%
Basic scenario 2 (39 fishing methods)	17.41%	17.41%	4.52%	4.52%	108.01%	43.36%	16.18%
2 outputs; each species and other species							
Japanese sardine	8.94%	8.94%	1.86%	1.49%	105.74%	27.65%	8.67%
Japanese jack mackerel	9.63%	9.63%	1.31%	1.06%	108.13%	30.47%	9.77%
Mackerel	9.70%	9.70%	1.38%	1.13%	106.95%	29.38%	9.82%
Pacific saury	10.24%	10.24%	1.68%	1.36%	104.93%	37.58%	12.05%
Alaska Pollock	10.35%	10.35%	1.82%	1.38%	104.17%	35.01%	10.98%
Queen crab	8.86%	8.86%	1.64%	1.23%	100.84%	32.57%	8.98%
Japanese Common Squid	10.74%	10.74%	1.96%	1.47%	106.71%	30.43%	10.05%
TAC (a total of above 7 species)	11.72%	11.72%	1.85%	1.56%	105.51%	38.01%	12.15%
3 outputs;							

TAC, other fish and other marine animals							
Basic scenario (10 fishing methods)	14.71%	14.71%	3.63%	2.79%	102.92%	42.55%	15.98%
Seasonal closure	15.59%	15.59%	5.58%	4.00%	98.49%	43.50%	16.83%
Technical inefficiency	17.49%	17.49%	8.30%	5.30%	107.09%	44.49%	19.39%
Upper bounds	16.18%	16.18%	6.05%	4.71%	93.71%	43.45%	16.90%
Lower bounds	20.85%	20.85%	192.63%	194.29%	34.82%	48.30%	21.65%
Basic scenario 2 (39 fishing methods)	18.72%	18.72%	4.82%	4.17%	106.09%	47.33%	18.62%
3 outputs; each species, other fish and other marine animals							
Japanese sardine	11.26%	11.26%	2.71%	1.96%	107.19%	32.14%	11.79%
Japanese jack mackerel	11.68%	11.68%	2.73%	1.98%	107.58%	33.79%	12.57%
Mackerel	11.87%	11.87%	2.80%	2.11%	106.84%	32.98%	12.57%
Pacific saury	12.66%	12.66%	3.29%	2.37%	105.66%	38.59%	14.20%
Alaska Pollock	12.25%	12.25%	4.52%	2.69%	105.10%	36.34%	13.30%
Queen crab	11.28%	11.28%	2.46%	1.79%	106.39%	31.25%	11.77%
Japanese Common Squid	14.22%	14.22%	21.73%	9.23%	105.23%	39.51%	14.98%

Table A9. Optimum Amounts of Inputs (per each fishery type)

	Fishing type 1									
	1	2	3	4	5	6	7	8	9	10
Current situation										
# of DMUs	898	488	24	204	1546	176	1145	96	707	2199
Tonnage	106404.2	40993.8	166.7	79446.5	65629.1	17062.5	38003.0	1903.9	216612.6	166684.1
kilowatt	528555.1	405297.2	1920.6	356263.8	860131.8	103705.7	352931.3	20838.6	609836.3	1314901.5
Fishing days (average)	161.1	158.4	132.1	199.5	155.0	173.0	204.3	146.5	189.9	140.8
Labor	23127.9	12333.1	547.0	10565.1	32238.4	3521.8	22853.2	793.8	20242.6	43578.1
1 output;										
Production value										
Basic scenario										
(10 fishing methods)										
# of DMUs	249	53	6	57	363	31	541	4	77	627
Tonnage	1.21%	0.99%	1.52%	3.84%	0.84%	4.00%	5.87%	0.08%	1.44%	0.96%
kilowatt	2.09%	0.63%	1.36%	3.24%	0.92%	1.93%	5.09%	0.11%	0.84%	1.01%
Fishing days (average)	87.39%	79.66%	74.91%	80.31%	79.49%	105.37%	79.82%	95.97%	102.55%	88.28%
Labor	35.42%	12.98%	18.92%	20.98%	22.90%	25.23%	91.20%	8.08%	8.36%	51.45%
Seasonal closure										
# of DMUs	259	57	6	57	369	31	542	4	87	639
Tonnage	1.51%	1.13%	1.56%	3.04%	0.88%	4.16%	6.60%	0.08%	5.55%	2.28%
kilowatt	2.57%	0.75%	1.40%	2.56%	0.95%	2.04%	5.72%	0.12%	2.75%	1.51%
Fishing days (average)	86.02%	73.22%	74.91%	78.46%	79.89%	98.33%	75.81%	95.97%	87.23%	87.90%

Labor	37.11%	13.39%	18.92%	21.81%	23.20%	24.16%	88.89%	8.08%	8.35%	51.68%
Technical inefficiency										
# of DMUs	332	115	8	117	411	28	797	11	158	524
Tonnage	3.61%	3.20%	3.03%	6.12%	1.61%	5.99%	12.34%	2.61%	3.44%	1.82%
kilowatt	5.09%	2.32%	3.07%	6.64%	1.60%	2.70%	10.88%	1.47%	2.94%	1.78%
Fishing days (average)	95.70%	79.83%	74.52%	92.36%	78.65%	103.32%	85.91%	85.63%	95.41%	91.65%
Labor	42.44%	37.63%	29.04%	48.70%	24.79%	22.72%	131.98%	16.09%	16.31%	51.03%
Upper bounds										
# of DMUs	276	61	6	61	387	31	564	5	99	679
Tonnage	2.06%	1.37%	1.82%	2.90%	1.12%	4.81%	7.65%	0.11%	3.17%	1.25%
kilowatt	3.93%	0.92%	1.64%	2.68%	1.22%	2.32%	6.72%	0.15%	1.85%	1.33%
Fishing days (average)	79.07%	75.19%	67.42%	76.87%	72.12%	94.83%	72.59%	82.12%	91.78%	80.86%
Labor	37.34%	14.63%	17.03%	22.70%	22.13%	22.71%	86.09%	7.91%	9.43%	51.35%
Lower bounds										
# of DMUs	898	488	24	204	1546	176	1145	96	707	2199
Tonnage	162.82%	258.73%	210.63%	171.27%	177.53%	162.14%	107.69%	186.24%	167.36%	169.52%
kilowatt	161.60%	257.31%	201.37%	166.39%	181.65%	181.60%	121.36%	186.97%	169.91%	168.18%
Fishing days (average)	25.65%	12.43%	24.69%	23.36%	23.78%	22.99%	39.87%	11.47%	16.75%	25.05%
Labor	35.31%	28.63%	27.72%	23.18%	34.11%	32.39%	92.32%	22.51%	17.53%	48.94%
Basic scenario 2*										
(39 fishing methods)										
# of DMUs	289	99	7	73	669	26	648	10	186	591
Tonnage	3.80%	3.74%	2.87%	5.29%	3.04%	6.28%	9.63%	0.98%	3.54%	2.24%

kilowatt	6.11%	2.96%	2.63%	6.07%	3.22%	3.09%	8.25%	0.87%	2.97%	1.99%
Fishing days (average)	99.23%	86.21%	83.68%	73.98%	79.91%	106.28%	93.21%	96.73%	89.50%	102.19%
Labor	38.54%	28.88%	20.75%	45.15%	40.43%	22.90%	101.75%	19.14%	20.72%	51.10%
1 output;										
Production quantity										
Basic scenario										
(10 fishing methods)										
# of DMUs	227	17	2	107	150	34	549	3	0	384
Tonnage	0.61%	0.46%	0.16%	3.37%	0.19%	3.09%	3.81%	0.03%	-	0.22%
kilowatt	0.82%	0.24%	0.13%	3.32%	0.20%	1.90%	3.03%	0.05%	-	0.19%
Fishing days (average)	89.36%	33.66%	78.74%	92.99%	71.50%	104.66%	78.20%	94.40%	-	89.83%
Labor	22.24%	4.97%	4.20%	55.22%	7.20%	26.52%	92.11%	5.75%	-	44.10%
Seasonal closure										
# of DMUs	253	21	2	116	158	37	580	3	0	398
Tonnage	0.69%	0.53%	0.16%	16.61%	0.21%	5.86%	4.32%	0.03%	-	0.25%
kilowatt	0.91%	0.28%	0.14%	11.30%	0.22%	5.01%	3.44%	0.05%	-	0.23%
Fishing days (average)	88.71%	47.34%	78.74%	84.37%	72.51%	96.74%	74.35%	94.40%	-	88.49%
Labor	23.33%	6.36%	4.20%	53.70%	7.66%	29.46%	93.19%	5.75%	-	44.85%
Technical inefficiency										
# of DMUs	254	46	3	138	86	37	631	5	0	57
Tonnage	1.36%	1.02%	1.20%	11.69%	0.10%	6.11%	5.97%	0.09%	-	0.09%
kilowatt	1.91%	0.60%	1.06%	10.62%	0.10%	3.62%	5.06%	0.14%	-	0.06%
Fishing days (average)	102.08%	57.53%	97.92%	94.55%	68.80%	104.59%	81.66%	91.19%	-	83.49%

Labor	27.83%	12.30%	16.09%	73.88%	4.29%	38.26%	107.01%	8.83%	-	3.40%
Upper bounds										
# of DMUs	258	25	2	120	169	37	598	3	0	403
Tonnage	1.06%	0.63%	0.19%	9.92%	0.27%	4.50%	5.28%	0.04%	-	0.30%
kilowatt	1.26%	0.34%	0.16%	8.28%	0.28%	2.40%	4.28%	0.06%	-	0.28%
Fishing days (average)	83.13%	57.60%	70.86%	82.12%	65.86%	94.74%	72.05%	84.96%	-	79.47%
Labor	23.50%	7.03%	3.78%	56.33%	7.50%	28.30%	91.31%	5.18%	-	40.81%
Lower bounds										
# of DMUs	898	488	24	204	1546	176	1145	96	707	2199
Tonnage	138.83%	234.42%	197.59%	123.69%	157.85%	127.18%	110.79%	160.46%	155.61%	162.55%
kilowatt	137.57%	232.71%	188.15%	116.83%	162.08%	149.40%	122.13%	161.09%	151.78%	154.49%
Fishing days (average)	23.21%	7.18%	13.74%	44.13%	14.24%	26.02%	32.66%	11.47%	9.46%	20.94%
Labor	24.70%	22.63%	14.47%	46.87%	21.17%	36.21%	80.47%	22.51%	11.27%	53.68%
Basic scenario 2*										
(39 fishing methods)										
# of DMUs	243	97	4	122	373	37	618	10	15	233
Tonnage	2.65%	9.25%	1.60%	9.06%	0.83%	8.68%	7.15%	0.49%	0.03%	0.84%
kilowatt	3.68%	7.83%	1.52%	9.02%	0.89%	4.51%	5.98%	0.47%	0.06%	0.48%
Fishing days (average)	101.71%	61.98%	79.50%	88.14%	75.16%	107.24%	93.25%	96.46%	103.72%	99.84%
Labor	31.09%	27.86%	17.37%	83.33%	18.73%	41.96%	98.58%	17.38%	0.89%	29.12%

2 outputs;

TAC and other species

Basic scenario										
(10 fishing methods)										
# of DMUs	253	55	4	144	265	35	730	7	2	385
Tonnage	2.38%	1.37%	1.42%	6.53%	0.46%	6.99%	6.29%	0.19%	0.01%	0.82%
kilowatt	2.50%	0.89%	1.34%	6.57%	0.49%	4.38%	5.46%	0.17%	0.01%	0.57%
Fishing days (average)	97.86%	78.82%	79.50%	87.26%	72.82%	106.57%	85.35%	73.88%	88.74%	96.26%
Labor	35.24%	16.35%	17.37%	72.45%	12.36%	45.65%	106.47%	12.90%	0.17%	37.99%
Seasonal closure										
# of DMUs	282	74	4	156	293	36	752	9	3	434
Tonnage	11.25%	2.69%	1.50%	14.62%	0.56%	10.89%	8.74%	0.62%	0.01%	1.49%
kilowatt	4.91%	2.08%	1.42%	13.03%	0.59%	5.93%	7.18%	0.50%	0.02%	0.83%
Fishing days (average)	94.02%	66.28%	79.50%	81.70%	73.85%	98.03%	73.94%	70.67%	81.00%	95.12%
Labor	38.52%	29.63%	17.37%	74.36%	13.51%	46.27%	103.10%	16.76%	0.20%	42.32%
Technical inefficiency										
# of DMUs	327	89	4	162	283	36	833	17	19	115
Tonnage	3.98%	4.24%	1.73%	8.31%	0.49%	13.98%	9.91%	1.88%	0.03%	1.34%
kilowatt	3.96%	3.41%	1.64%	9.79%	0.48%	7.32%	8.90%	1.78%	0.06%	0.44%
Fishing days (average)	100.42%	70.27%	79.50%	89.05%	84.64%	103.92%	88.98%	84.98%	102.94%	107.53%
Labor	41.69%	40.99%	17.37%	86.50%	18.62%	46.28%	123.33%	26.68%	1.14%	9.25%
Upper bounds	282	73	4	154	300	38	796	9	13	444
# of DMUs	11.47%	3.07%	1.75%	8.02%	0.75%	9.86%	9.43%	0.65%	0.03%	1.53%
Tonnage	16.49%	2.39%	1.66%	8.69%	0.75%	5.94%	8.19%	0.60%	0.08%	0.95%
kilowatt	89.16%	67.71%	71.55%	79.46%	67.09%	95.73%	76.92%	67.24%	65.64%	92.35%

Fishing days (average)	35.45%	27.98%	15.63%	72.33%	12.94%	44.27%	112.11%	15.74%	1.28%	36.70%
Labor										
Lower bounds										
# of DMUs	898	488	24	204	1546	176	1145	96	707	2199
Tonnage	147.14%	277.23%	225.55%	139.70%	193.74%	128.65%	116.93%	194.66%	190.54%	182.97%
kilowatt	157.51%	275.81%	215.79%	130.63%	198.32%	155.39%	129.49%	195.78%	191.71%	174.49%
Fishing days (average)	31.07%	12.79%	18.85%	56.28%	18.04%	27.64%	48.11%	13.10%	9.40%	21.68%
Labor	39.14%	31.25%	25.17%	65.65%	25.57%	54.54%	99.85%	27.48%	11.65%	48.71%
Basic scenario 2*										
(39 fishing methods)										
# of DMUs	330	183	4	147	448	44	781	10	34	253
Tonnage	6.69%	7.13%	2.10%	11.80%	8.75%	7.22%	10.14%	0.99%	0.16%	1.48%
kilowatt	6.81%	5.95%	2.00%	12.21%	8.30%	5.18%	8.82%	0.89%	0.37%	0.79%
Fishing days (average)	103.80%	73.79%	79.50%	90.35%	76.69%	93.70%	92.65%	84.18%	107.30%	103.98%
Labor	43.97%	60.12%	17.37%	95.73%	21.98%	47.41%	111.43%	18.94%	3.07%	24.89%
2 outputs;										
each species and other species										
Japanese sardine										
# of DMUs	245	27	2	156	175	29	567	4	0	187
Tonnage	1.00%	0.63%	0.18%	10.94%	0.28%	8.25%	4.80%	0.10%	-	0.12%
kilowatt	1.36%	0.34%	0.15%	12.33%	0.30%	3.97%	4.06%	0.10%	-	0.11%
Fishing days (average)	88.64%	63.08%	78.74%	86.78%	73.67%	98.54%	81.83%	84.45%	-	87.54%
Labor	24.73%	8.27%	4.20%	74.71%	8.58%	25.13%	91.72%	8.02%	-	17.49%

Japanese jack mackerel										
# of DMUs	239	38	3	129	199	30	663	7	1	228
Tonnage	1.35%	0.90%	1.13%	4.73%	0.33%	6.59%	5.52%	0.16%	0.00%	0.35%
kilowatt	1.48%	0.57%	0.99%	4.66%	0.35%	3.08%	4.67%	0.17%	0.00%	0.23%
Fishing days (average)	90.14%	68.90%	97.92%	90.54%	73.59%	100.58%	85.23%	90.34%	115.86%	88.30%
Labor	25.49%	11.65%	16.09%	62.86%	10.10%	28.85%	105.44%	12.01%	0.01%	21.13%
Mackerel										
# of DMUs	231	42	4	138	195	38	631	15	1	228
Tonnage	0.87%	0.96%	1.17%	6.19%	0.32%	5.28%	5.85%	1.09%	0.00%	0.32%
kilowatt	1.13%	0.60%	1.11%	5.83%	0.34%	3.25%	4.88%	1.04%	0.00%	0.23%
Fishing days (average)	90.29%	66.36%	79.50%	87.70%	73.60%	89.43%	84.98%	84.44%	115.86%	91.46%
Labor	23.73%	12.33%	17.37%	67.67%	9.90%	28.45%	101.57%	24.17%	0.01%	18.44%
Pacific saury										
# of DMUs	233	37	4	109	432	32	719	7	1	278
Tonnage	2.00%	0.99%	1.24%	5.65%	0.82%	6.19%	6.27%	0.17%	0.00%	0.78%
kilowatt	1.93%	0.62%	1.17%	5.23%	0.76%	3.62%	5.33%	0.18%	0.00%	0.47%
Fishing days (average)	90.63%	58.90%	79.50%	82.55%	84.86%	102.39%	84.41%	90.34%	115.86%	91.62%
Labor	22.30%	11.00%	17.37%	68.24%	30.93%	40.45%	110.89%	12.01%	0.01%	30.21%
Alaska Pollock	236	22	2	119	534	37	678	3	54	217
# of DMUs	3.41%	0.60%	0.21%	7.19%	0.96%	4.58%	5.24%	0.04%	0.04%	0.15%
Tonnage	3.13%	0.32%	0.18%	6.47%	0.84%	2.68%	4.34%	0.07%	0.14%	0.14%
kilowatt	98.55%	68.62%	78.74%	89.96%	77.94%	106.78%	84.23%	94.40%	64.19%	91.56%
Fishing days (average)	30.65%	7.03%	4.20%	55.66%	30.51%	31.06%	101.22%	5.75%	3.84%	24.54%

Labor										
Queen crab										
# of DMUs	294	17	2	104	210	35	514	3	0	385
Tonnage	6.16%	0.51%	0.18%	3.37%	0.26%	3.73%	3.80%	0.04%	-	0.20%
kilowatt	5.57%	0.28%	0.15%	3.42%	0.25%	2.33%	3.11%	0.06%	-	0.22%
Fishing days (average)	92.45%	41.72%	78.74%	91.64%	70.09%	105.39%	78.00%	94.40%	-	89.75%
Labor	29.35%	5.09%	4.20%	48.78%	9.41%	27.65%	84.95%	5.75%	-	44.15%
Japanese Common Squid										
# of DMUs	236	24	3	135	205	27	676	4	0	344
Tonnage	3.01%	0.64%	1.26%	5.34%	0.37%	3.94%	6.01%	0.08%	-	2.08%
kilowatt	2.51%	0.35%	1.11%	5.88%	0.39%	1.90%	4.99%	0.11%	-	0.88%
Fishing days (average)	93.78%	69.16%	97.92%	91.37%	72.11%	103.97%	83.72%	95.97%	-	91.61%
Labor	27.55%	7.45%	16.09%	60.06%	9.70%	23.32%	106.18%	8.08%	-	22.17%
3 outputs; TAC, other fish and other marine animals										
Basic scenario (10 fishing methods)										
# of DMUs	457	100	4	142	347	40	777	11	8	463
Tonnage	4.66%	3.20%	1.78%	12.97%	0.71%	8.15%	9.23%	0.72%	0.02%	2.75%
kilowatt	5.07%	2.53%	1.69%	11.65%	0.73%	5.41%	8.10%	0.69%	0.03%	1.18%
Fishing days (average)	98.89%	74.60%	79.50%	81.50%	74.26%	99.40%	85.68%	76.86%	99.79%	102.59%
Labor	48.13%	33.79%	17.37%	85.62%	16.15%	47.62%	124.19%	20.54%	0.35%	28.26%

Seasonal closure										
# of DMUs	472	142	4	152	383	49	827	12	26	488
Tonnage	7.66%	4.90%	1.88%	23.52%	0.91%	8.40%	11.64%	0.87%	0.05%	3.28%
kilowatt	7.77%	3.96%	1.79%	19.43%	0.93%	5.53%	10.08%	0.81%	0.10%	1.43%
Fishing days (average)	95.37%	72.84%	79.50%	76.76%	75.27%	87.49%	75.04%	77.06%	91.02%	102.58%
Labor	49.76%	42.92%	17.37%	91.32%	17.89%	52.79%	118.24%	22.04%	1.16%	28.12%
Technical inefficiency										
# of DMUs	507	176	4	155	340	43	872	19	38	204
Tonnage	6.50%	8.22%	2.11%	47.21%	0.74%	9.44%	12.36%	0.87%	0.09%	3.61%
kilowatt	7.02%	6.71%	2.00%	35.99%	0.74%	6.07%	10.90%	1.89%	0.21%	1.25%
Fishing days (average)	101.41%	61.34%	79.50%	81.50%	83.68%	96.09%	89.62%	90.95%	108.94%	105.26%
Labor	54.67%	65.67%	17.37%	96.95%	20.49%	49.43%	132.07%	28.74%	2.42%	11.98%
Upper bounds										
# of DMUs	500	129	4	150	403	44	848	12	41	519
Tonnage	8.10%	5.11%	2.17%	24.81%	1.17%	9.91%	12.96%	1.00%	0.09%	3.79%
kilowatt	10.46%	4.13%	2.06%	21.00%	1.17%	6.43%	11.44%	0.94%	0.25%	1.79%
Fishing days (average)	89.68%	64.67%	71.55%	74.51%	68.87%	87.55%	78.23%	69.35%	77.71%	96.64%
Labor	48.24%	38.65%	15.63%	86.92%	18.24%	45.66%	124.26%	19.83%	2.83%	27.48%
Lower bounds										
# of DMUs	898	488	24	204	1546	176	1145	96	707	2199
Tonnage	166.03%	304.33%	255.85%	146.21%	218.66%	163.28%	115.89%	220.08%	216.70%	182.88%
kilowatt	170.26%	303.47%	243.29%	146.26%	223.84%	182.50%	131.40%	220.89%	217.41%	177.10%
Fishing days (average)	45.37%	16.36%	19.76%	53.29%	21.49%	27.40%	56.88%	15.66%	9.27%	24.65%

Labor	49.45%	41.87%	26.32%	79.82%	28.66%	52.30%	121.66%	32.31%	11.63%	35.20%
Basic scenario 2*										
(39 fishing methods)										
# of DMUs	507	227	4	140	470	44	831	13	43	275
Tonnage	7.55%	8.51%	2.26%	12.79%	1.50%	7.75%	13.99%	1.38%	0.31%	3.19%
kilowatt	7.54%	7.12%	2.15%	14.51%	1.57%	5.57%	12.23%	1.25%	0.64%	1.29%
Fishing days (average)	90.57%	68.24%	79.50%	88.52%	77.45%	94.14%	91.65%	83.19%	102.50%	107.80%
Labor	57.53%	68.33%	17.37%	89.90%	24.61%	47.32%	122.57%	25.08%	3.85%	23.98%
3 outputs;										
Each species, other fish and										
other marine animals										
Japanese sardine										
# of DMUs	355	42	3	149	188	29	723	7	0	224
Tonnage	2.21%	1.08%	1.32%	10.90%	0.38%	4.23%	7.55%	0.20%	-	2.73%
kilowatt	2.78%	0.67%	1.16%	10.67%	0.42%	2.42%	6.35%	0.23%	-	0.82%
Fishing days (average)	94.55%	70.58%	97.92%	87.59%	72.58%	111.17%	84.09%	87.35%	-	90.94%
Labor	39.36%	12.68%	16.09%	65.76%	9.09%	37.78%	115.94%	13.39%	-	13.79%
Japanese jack mackerel										
# of DMUs	327	42	3	132	256	36	818	7	1	242
Tonnage	2.84%	1.10%	1.37%	9.28%	0.50%	7.08%	8.09%	0.20%	0.00%	2.72%
kilowatt	3.00%	0.72%	1.20%	9.10%	0.55%	3.56%	6.94%	0.20%	0.00%	0.87%
Fishing days (average)	95.03%	75.24%	97.92%	88.74%	72.84%	106.43%	85.46%	90.34%	115.86%	92.63%
Labor	38.01%	12.66%	16.09%	56.70%	12.08%	46.95%	127.65%	12.01%	0.02%	14.06%

Mackerel										
# of DMUs	336	45	4	140	238	46	765	17	0	275
Tonnage	3.95%	1.19%	1.44%	8.20%	0.59%	8.19%	8.22%	1.38%	-	2.64%
kilowatt	3.65%	0.76%	1.36%	9.27%	0.62%	4.75%	6.91%	1.33%	-	0.89%
Fishing days (average)	94.95%	70.45%	79.50%	86.97%	71.75%	92.52%	85.65%	85.22%	-	90.29%
Labor	38.89%	13.19%	17.37%	61.77%	11.28%	47.29%	116.57%	27.66%	-	15.13%
Pacific saury										
# of DMUs	325	47	3	125	494	33	826	7	1	246
Tonnage	2.59%	1.28%	1.48%	11.84%	1.43%	8.40%	8.54%	0.21%	0.00%	3.47%
kilowatt	2.88%	0.83%	1.31%	10.45%	1.31%	4.92%	7.36%	0.22%	0.00%	1.18%
Fishing days (average)	96.42%	74.17%	97.92%	83.37%	83.37%	103.30%	86.68%	90.34%	115.86%	92.16%
Labor	38.40%	13.79%	16.09%	73.40%	33.73%	40.27%	125.13%	12.01%	0.01%	13.98%
Alaska Pollock										
# of DMUs	368	40	2	127	552	31	743	4	44	191
Tonnage	5.87%	1.21%	0.25%	18.72%	1.43%	8.49%	7.76%	0.09%	0.04%	3.67%
kilowatt	5.24%	0.75%	0.21%	13.41%	1.45%	4.57%	6.55%	0.13%	0.15%	0.90%
Fishing days (average)	98.67%	79.77%	78.74%	90.60%	78.35%	101.29%	86.56%	95.97%	62.47%	89.14%
Labor	47.67%	12.01%	4.20%	52.88%	31.69%	39.22%	114.44%	8.08%	3.30%	11.72%
Queen crab										
# of DMUs	424	40	3	123	248	30	668	4	0	245
Tonnage	5.77%	1.03%	1.32%	3.73%	0.42%	6.61%	6.43%	0.08%	-	2.79%
kilowatt	5.56%	0.65%	1.16%	4.81%	0.43%	3.23%	5.25%	0.12%	-	0.86%
Fishing days (average)	95.47%	72.93%	97.92%	90.53%	71.69%	101.90%	84.98%	95.97%	-	85.17%

Labor	49.53%	12.34%	16.09%	49.10%	11.32%	41.19%	103.73%	8.08%	-	13.62%
Japanese Common Squid										
# of DMUs	457	59	4	131	305	34	752	7	0	443
Tonnage	4.36%	2.17%	1.72%	176.83%	0.68%	23.56%	8.80%	0.17%	-	3.27%
kilowatt	4.66%	1.62%	1.63%	100.60%	0.73%	13.97%	7.37%	0.24%	-	1.66%
Fishing days (average)	98.38%	66.50%	79.50%	83.78%	72.90%	103.25%	86.43%	98.57%	-	89.61%
Labor	47.71%	21.67%	17.37%	79.26%	14.15%	39.63%	117.05%	11.50%	-	27.81%

TableA10. Capacity Utilization by fishery type

					Fishery type 1				Fishery type 2			
					Production value (Yen)		Estimated Production Quantities (tons)		Production value		Estimated Production Quantities	
Fishery type1	Fishery type2	Pelagic fishery	Offshore fishery	Coastal fishery	CUoo	CUeo	CUoo	CUeo	CUoo	CUeo	CUoo	CUeo
Total		✓	✓	✓	0.245	0.372	0.304	0.441	0.414	0.571	0.476	0.640
1		✓	✓	✓	0.125	0.190	0.239	0.347	0.314	0.437	0.410	0.548
	1	✓			0.328	0.773	0.405	0.905	1.000	1.000	1.000	1.000
	2	✓			0.605	0.712	0.576	0.777	0.984	0.991	0.984	0.991
	3		✓		0.503	0.667	0.605	0.766	0.790	0.884	0.790	0.884
	4		✓		0.822	0.930	0.426	0.478	0.931	0.999	0.931	0.999
	5		✓	✓	0.120	0.181	0.097	0.135	0.124	0.186	0.124	0.186
	6		✓	✓	0.075	0.116	0.162	0.241	0.314	0.446	0.314	0.446
	7		✓	✓	0.146	0.170	0.048	0.065	0.922	0.958	0.922	0.958
2			✓	✓	0.357	0.551	0.347	0.535	0.389	0.591	0.386	0.590
	8		✓	✓	0.377	0.580	0.382	0.587	0.382	0.589	0.382	0.589
	9		✓	✓	0.266	0.416	0.167	0.261	0.442	0.601	0.442	0.601
3	10			✓	0.794	0.874	0.794	0.874	0.794	0.874	0.794	0.874
4		✓	✓	✓	0.564	0.658	0.476	0.588	0.752	0.881	0.737	0.878
	11	✓			0.933	0.973	0.696	0.822	1.000	1.000	1.000	1.000
	12		✓		0.724	0.832	0.270	0.408	0.894	0.894	0.894	0.894
	13		✓		0.674	0.781	0.727	0.849	0.772	0.930	0.772	0.930
	14		✓		0.707	0.729	0.940	0.969	1.000	1.000	1.000	1.000
	15		✓	✓	0.364	0.438	0.260	0.328	0.575	0.747	0.575	0.747
	16		✓	✓	0.386	0.448	0.363	0.457	0.598	0.726	0.598	0.726
	17		✓	✓	0.253	0.399	0.191	0.316	0.685	0.878	0.685	0.878
5			✓	✓	0.231	0.318	0.231	0.313	0.238	0.341	0.236	0.339
	18		✓	✓	0.350	0.569	0.219	0.345	0.533	0.877	0.533	0.877
	19		✓	✓	0.742	0.884	0.810	0.897	0.992	1.000	0.992	1.000
	20		✓	✓	0.224	0.307	0.226	0.305	0.228	0.328	0.228	0.328
6			✓	✓	0.668	0.792	0.652	0.768	0.709	0.818	0.710	0.814
	21		✓	✓	0.702	0.807	0.709	0.808	0.710	0.810	0.710	0.810
	22		✓	✓	0.564	0.738	0.383	0.536	0.703	0.852	0.703	0.852
7				✓	0.251	0.363	0.246	0.360	0.374	0.517	0.377	0.525
	23			✓	0.331	0.428	0.320	0.418	0.370	0.490	0.370	0.490
	24			✓	0.402	0.592	0.402	0.594	0.408	0.610	0.408	0.610
	25			✓	0.139	0.219	0.123	0.197	0.351	0.488	0.351	0.488
8	26		✓	✓	0.486	0.642	0.486	0.642	0.486	0.642	0.486	0.642
9		✓	✓	✓	0.625	0.701	0.577	0.655	0.699	0.780	0.685	0.776

	27	✓			0.701	0.759	0.638	0.696	0.747	0.800	0.747	0.800
	28		✓		0.659	0.719	0.746	0.824	0.785	0.869	0.785	0.869
	29		✓	✓	0.510	0.641	0.466	0.571	0.755	0.883	0.755	0.883
	30		✓	✓	0.402	0.503	0.382	0.472	0.483	0.625	0.483	0.625
10		✓	✓	✓	0.183	0.394	0.188	0.370	0.371	0.614	0.443	0.716
	31	✓			0.825	0.884	0.869	0.919	0.918	0.998	0.918	0.998
	32		✓		0.795	0.865	0.801	0.865	0.904	0.969	0.904	0.969
	33		✓	✓	0.245	0.529	0.231	0.448	0.575	0.681	0.575	0.681
	34	✓			0.730	0.816	0.801	0.889	0.993	0.993	0.993	0.993
	35		✓		0.587	0.788	0.604	0.797	0.872	0.940	0.872	0.940
	36		✓	✓	0.203	0.503	0.188	0.423	0.218	0.542	0.218	0.542
	37		✓	✓	0.184	0.340	0.194	0.314	0.851	0.933	0.851	0.933
	38		✓	✓	0.099	0.284	0.080	0.215	0.359	0.594	0.359	0.594
	39		✓	✓	0.091	0.206	0.041	0.088	0.317	0.437	0.317	0.437